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Faculty of Science

Natural Radioactivity for Different Water Samples in Qena Governorate

A Thesis

Submitted to the Faculty of Science
South Valley University

For

The Degree of M. Sc. in Physics

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2014

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AKNOWLEDGEMENT

ACKNOWLEDGEMENT

Above all, I do indeed thank ALLAH who guided and aided me to bring-forth to light this humble work through his lights.

I am indebted to *Prof. Dr. Abd El-Basset Abbady Mohamed*, Professor of nuclear and radiation physics, Physics Department, Faculty of Science, South Valley University, for his kind supervision and guidance during the progress of the work.

My deep thanks and gratitude to *Dr. Shaban Ramadan Mohamed Harb*, Assist. Prof. of radiation physics, Physics Department, Faculty of Science, South Valley University, for his supervising, grateful assistance, continues encouragement and valuable advises and discussions throughout the work.

I would like to express my deep thanks and utmost appreciated to *Dr. Khaled Salah El Din Ebrahim*, Assist. Prof. of radiation physics, Physics Department, Faculty of Science, South Valley University, for continuous help, encouragement and human kindness and his continuous supervision and fruitful discussions are also acknowledged.

I wish to express my great thanks to *Prof. Dr. Abd El hady M. Ibrahim*, Dean of Faculty of Science, South Valley University, and I wish to thank *Dr. A. A. Ebnalwaled* head of Physics Department., Faculty of Science, South Valley University, for their sponsoring of this work.

I am grateful to my family for their love and support, I wish also to thank my lovely wife *Hoda* for her love and support.

I am grateful to my dear friends and to my colleague and all staff members at faculty of science for their encouragement and for their assistance.

ABSTRACT

ABSTRACT

Radionuclides are naturally present throughout all environments, in varying amounts in air, water, plants, soil, rocks and etc. Naturally – occurring radionuclide's are mainly derived from three separate decay chains (^{238}U , ^{235}U , and ^{232}Th), and singly occurring ^{40}K . These radionuclides may enter the human body from eating, drinking, external exposure or by inhaling. Then they penetrate into tissue and its cells, which causes ionization effects to its basic matter "cytoplasm".

^{222}Rn is a colorless, odorless, tasteless, radioactive noble gas, which arises from the radioactive decay of ^{226}Ra (itself a decay product of ^{238}U). It is present in almost all rock, soil, and water, and typically moves up through the ground to the air above and into buildings through cracks and other holes in the underlying foundation. ^{222}Rn is one of the most significant of the avoidable hazards in the environment, typically accounting for more than 50% of the dose to an average population.

Measurements of natural radioactivity and radon levels in water samples from Qena governorate, Egypt, and their human impact are outlined in this thesis. This was performed by collecting two hundred twenty water samples (ground, drinking tap and mineral water) from different sites in Qena, and employing Alpha GUARD monitoring system to determine the activity concentrations of ^{222}Rn , also gamma spectrometry "NaI(Tl)" was used to determine the activity concentrations of ^{222}Rn , ^{226}Ra , ^{232}Th and ^{40}K in ground water.

In ground water samples ^{222}Rn activity concentrations were fluctuated between 0.04 ± 0.025 and 10.07 ± 0.219 Bq/l, with an average value of 3.57 ± 0.077 Bq/l.

In order to check the obtained results, two radon measuring techniques (Alpha GUARD and gamma spectrometry) were applied for measure some ground water samples from all sites, and the obtained results show that the two radon measuring techniques results are in a good agreement.

In the measuring ground water samples, the obtained measuring results for ^{226}Ra , ^{232}Th and ^{40}K activity concentrations were fluctuated between (0.126 ± 0.007 and 1.93 ± 0.117), (0.037 ± 0.003 and 0.899 ± 0.077) and (3.18 ± 0.273 and 7 ± 0.602), with

averages values of 0.54 ± 0.029 , 0.4 ± 0.027 and 5.10 ± 0.44 Bq/l, for ^{226}Ra , ^{232}Th and ^{40}K , respectively.

In the investigated drinking tap water samples, the obtained results for ^{222}Rn activity concentrations show that, the activity concentrations were ranged between 0.006 ± 0.0005 and 0.117 ± 0.0027 Bq/l, with an average value of 0.049 ± 0.003 Bq/l.

The obtained results for ^{222}Rn activity concentrations in the investigated mineral water samples show that, the activity concentrations were fluctuated between 0.014 ± 0.003 and 0.237 ± 0.005 Bq/l, with an average value of 0.077 ± 0.002 Bq/l.

The impacts of geochemical parameters of water such as PH, conductivity and TDS on the natural radionuclides activity concentration were studied, a reasonable correlation between pH and the ^{222}Rn , ^{226}Ra and ^{232}Th activity concentrations were found, in which the activity concentrations decreased with increasing PH, whereas no general trend was observed that related the radionuclides activity concentrations with conductivity and TDS.

Health aspects are discussed, based on calculation of the annual effective doses for different age groups, which found in values lower than the reference level.

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INTRODUCTION

INTRODUCTION

1 Radioactivity and Radionuclides

Radiations are with us all the time. They are present in varying amounts in air, water, plants, animals, soil and rocks. We are radioactive; we ingest appreciable amounts of radioactive potassium (^{40}K) and radiocarbon (^{14}C), as well as minute amounts of radioactive uranium, thorium, tritium, polonium and radium. We inhale radioactive ^{222}Rn and its daughters, other naturally occurring radioactive gases and particulates, and small amounts of radioactive materials present in the atmosphere from nuclear weapons use, and testing of decades ago. In addition, we are bombarded by cosmic rays, and we receive radiation from the ground, consumed products such as smoke detector, color television, and the medical x-rays (Douglas 1990).

The study of natural sources of radiation dates back to the year 1896, when Henri Becquerel, a French physicist, found that photographic plate was fogged when a sample of potassium sulphate uranyl was placed on top of it. After five years, radioactivity of uranium, thorium, polonium, radium and radon had been established (Stephen 1995). Rutherford showed that the emitted radiation was of three types: Alpha (α), beta (β) particles, and gamma (γ) rays. These rays are created in one of two types of spontaneous nuclear processes. It is known as radioactive decay process (As'ad 2004).

Every person on earth is exposed to natural radiation; majority of this radiation is naturally occurring and arises from three sources:

- Cosmic Radiation
- Cosmogenic Radiation
- Terrestrial Radiation

1.1 Cosmic Radiation

Cosmic radiation is the radiation originates from the sun and from outer space. The primary cosmic rays incident on the top of the earth's atmosphere are mainly protons (86%), α particles (11%) and electrons (2%), heavier nuclei make up the small remainder. These primary cosmic rays have a spectrum that extends from 1×10^8 to over 1×10^{20} eV.

In spite of extensive investigations, the various sources of cosmic rays are not well understood. However, all but the most energetic (above 1×10^{15} eV) are thought to originate in our own galaxy, possibly energized by the shock waves from supernovae (Thorne 2003). A still lower energy component of cosmic rays is generated near the surface of the sun by magnetic disturbances. The magnetic field of the Earth modulates cosmic ray intensity, resulting in minimum intensities and dose rates at the equator and maximum near the geomagnetic poles (UNSCEAR 2000).

1.2 Cosmogenic Radiation

Radionuclides formed by the interaction of cosmic rays with atoms in the atmosphere are known as cosmogenic radionuclides. These nuclides are produced in the stratosphere, as well as in the upper troposphere. Some of these cosmogenic radionuclides with half-lives above 1 day are listed in the following table 1. 1.

Because of their importance for human exposure ^3H , ^{14}C , ^7Be and ^{22}Na are of special interest. Natural ^3H is produced by the interaction of neutrons produced by cosmic radiation with nitrogen ^{14}N ($\text{n}, ^3\text{H}$) ^{12}C , or by ^6Li (n, α) ^3H interaction. ^3H is a radioactive isotope of hydrogen and predominately found in the atmosphere in water vapor and falls to earth in rain or snow. In nature, about 1 atom of ^3H exists for every 10^{18} atoms of ^1H . Because we are continuously ingesting foods and drinks containing hydrogen we will always have trace amounts of ^3H in our bodies. Natural ^{14}C is generated by ^{14}N (n, p) ^{14}C interaction. In the atmosphere ^{14}C is present in carbon dioxide, when it reaches the earth it becomes part of the carbon cycle. Since we continuously eat and breathe carbon-containing matter, we will always have some ^{14}C in our bodies. The specific activity of ^{14}C in natural samples has been assumed to be relatively constant at 7.5 pCi/g of total carbon for at least 15,000 years, prior to the advent of nuclear weapons testing (Hutchison 1997). ^7Be and ^{22}Na produced by cosmic radiation have not been studied as extensively as ^{14}C and ^3H and are not major contributors to our radiation exposure. The activity concentrations of ^7Be and ^{22}Na in surface air are stated to be 3000 and $0.3 \mu \text{Bq}/\text{m}^3$, respectively (UNSCEAR 1982).

Table1. 1 Some cosmogenic radionuclides, their production rates, and decay characteristics (UNSCEAR 1999, Rudolf 2012)

Radionuclide	Production rate (Atoms cm ⁻² .s ⁻¹)	t _½ (year)	Decay mode	Progeny nuclide
³ H	0.22/0.32	12.34	β^-	³ He
⁷ Be	0.040	0.146	EC	⁷ Li
¹⁰ Be	0.021	1.387x10	β^-	¹⁰ B
¹⁴ C	2.02	5,730	β^-	¹⁴ N
²⁶ Al	4.7x10 ⁻⁵	7.2x10 ⁵	EC	²⁶ Mg
³⁶ Cl	1.12x10 ⁻⁴	3.01x10 ⁵	EC (1.9%) β^- (98.1%)	³⁶ S ³⁶ Ar

1.3 Terrestrial Radiation

Terrestrial radiation radionuclides are mainly derived from three separate decay chains, Thorium–232 (²³²Th), Uranium–238 (²³⁸U) and Uranium–235 (²³⁵U), addition to the single radioactive potassium (⁴⁰K). The half-life times (t_½) of those radionuclides are comparable to the age of the earth. The uranium decay series begins with ²³⁸U which has a relative isotopic abundance of 99.27% and a half-life of 4.5×10^9 y. Thorium decay series begins with ²³²Th, which has a half-life of 1.4×10^{10} y, and relative abundance of essentially 100%. ⁴⁰K has a relative isotopic abundance of 0.0118% and a half-life of 1.3×10^9 y (Hutchison 1997).

1.3.1 Potassium

Potassium was discovered by Sir Humphry Davy in 1807 in London, by the electrolysis of potassium hydroxide (potash). This was the first metal to be isolated by electrolysis. This element is the seventh most abundant metal, it makes up 2.4% of earth crusts mass. Most minerals which containing potassium are sparingly soluble, but it is difficult to obtain the metal from them. However, certain minerals such as sylvite, sylvinite and carnallite were found in deposits formed by evaporation of old seas or lakes.

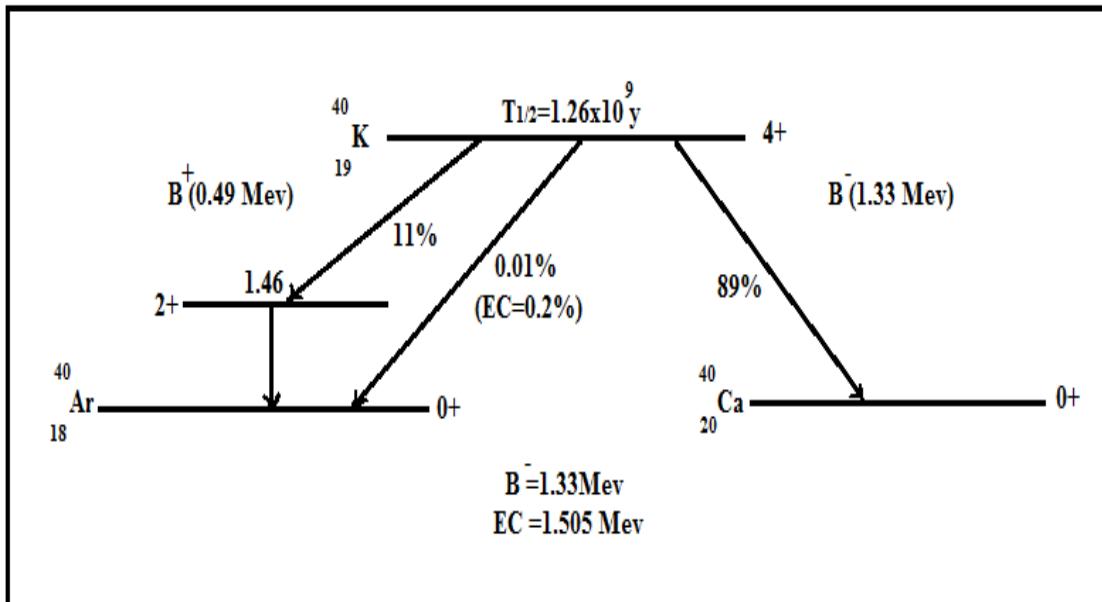
Potassium salts can be easily recovered from these minerals. This element is also found in the ocean with small amounts compared with sodium. Potassium appear as a soft, white metal which is silver when cut, but it rapidly oxidizes, so it must be preserved in a mineral oil such as kerosene. Potassium is the least dense metal known. It is also one of the most reactive and electropositive of metals. Because of rapidly oxidization of potassium in air, its reaction with water is vigorous. It catches fire spontaneously and decomposes with the evolution of hydrogen. Potassium and its salts give a violet color to a suitable flame. The greatest uses for potassium compounds are in fertilizers, nitrate, carbonate, chloride, bromide, cyanide and sulphates (Lide 2002).

Potassium is a member of the highly reactive group 1A alkali metal family. As shown in table 1. 2, potassium has three isotopes with mass numbers 39, 40, and 41. Only ^{40}K ($t_{1/2} = 1.28 \times 10^9$ y) is radioactive. It is essential to life, it is found in all living and formerly living things.

Table1. 2 Key isotopes of potassium (Lide 2002)

Nuclide	^{39}K	^{40}K	^{41}K
Atomic mass	38.964	39.974	40.962
Natural abundance	93.258%	0.0117%	6.730%
Half-Life time	Stable	1.28×10^9 y	Stable

The isotopic abundance of ^{40}K is small, only 0.012% of naturally occurring potassium, which gives a specific activity of 31.6 Bq/g of natural potassium, undergoes decay to stable ^{40}Ca (89%) of the time, emitting a 1.314 MeV max beta particle in the process. With the exception of a tiny fraction of decays ($1 \times 10^{-3}\%$) by electron capture (EC), ^{40}K undergoes decay by positron emission the remaining 11% of the time, emitting a characteristic photon with energy of 1460 keV. This photon is highly useful for identification and quantification of ^{40}K by gamma spectrometry, and makes an excellent calibration point because of the presence of potassium in essentially all environmental samples (Kathren 1984). The potassium decay scheme is illustrated in the following figure 1. 1.

Figure 1. 1 Decay scheme of ^{40}K (Lederer 1977)

1.3.2 Thorium

Thorium was discovered by J. J. Berzelius in 1828 in Stockholm, Sweden. Pure thorium appears as radioactive silvery, white metal, which retains its luster for several months. When contaminated with the oxide, thorium slowly tarnishes in air, it becoming first grey and then black. Thorium is found in large deposits in the USA and elsewhere, but these have not been exploited as a source of the element. Several methods are used to produce the metal, such as reducing thorium oxide with calcium by the electrolysis of anhydrous thorium chloride.

The principal use of thorium is in the Wels Bach mantle, which consists of thorium oxide amongst other compounds. This type of mantle glows with a dazzling flame when heated by gas so it is used in portable gas lights. Thorium is also an important alloying agent in magnesium, as it imparts greater strength and creep resistance at high temperatures. Thorium can be used as a source of nuclear power. It is about three times as abundant as uranium and about as abundant as lead, and there is probably more energy available from thorium than both uranium and fossil fuels.

Pure thorium one of the highest melting points of all elements. It is slowly attacked by water and acids. Powdered thorium metal is often pyrophoric. It turnings ignite when heated in air and burn with a brilliant white light (Lide 2002).

About the natural radioactivity of thorium, as shown in table 1. 3, the series includes alpha and beta emitting radionuclides. Longest lived member of the series is ^{232}Th ($t_{1/2} = 1.39 \times 10^{10}$ y). Its half-life time is about three times longer than the currently estimated age of the earth, permitting it and its decay products to occur in nature. The immediate parent of ^{232}Th is the alpha-emitter ^{236}U , but its half-life is only 2.4×10^7 y, therefore it no longer found in the nature. ^{236}U produced artificially in a variety of nuclear reactions, the thorium series terminates with the stable nuclide ^{208}Pb (Lide 2002).

Table1. 3 Key isotopes of thorium (Lide 2002)

Nuclide	^{228}Th	^{229}Th	^{230}Th	^{231}Th	^{232}Th	^{234}Th
Atomic mass	228.03	229.03	230.03	231.03	232.04	234.04
Natural abundance	trace	0%	trace	trace	100%	trace
Half-life time	1.9 y	7340 y	8×10^4 y	25.5 h	1.41×10^{10} y	24.1 d

1.3.2.1 ^{232}Th

The thorium series could be extended indefinitely to elements above ^{232}Th as follows: It is quite possible that several of these higher members of the series were present at the time the elements were formed, but 4.5×10^9 y later these precursors of ^{232}Th have decayed completely to the much longer-lived ^{232}Th . The accepted half-life of ^{232}Th is 1.39×10^{10} y. The main alpha particle group is 4.007 MeV (76%) and a weaker group has been detected with energy of 3.952 MeV (24%). A third alpha group has been observed with 0-2% intensity at energy 125 keV below the main group (Majumdar 1990).

1.3.2.2 ^{228}Ra

The daughter product of ^{232}Th decay is the 6.7% a beta-emitter ^{228}Ra . Since the total decay energy is only 55 keV, the radiations of ^{228}Ra are extremely weak and are

difficult to detect. The difficulty in the measurement of this isotope is caused by the presence of its short lived daughter ^{228}Ac ($t_{1/2} = 6.13\text{ h}$). The latter nuclide has a total beta-decay energy of 2110 keV and decays with the emission of a complex mixture of electrons and gamma rays. The daughter product of the ^{228}Ac decay is ^{228}Th . It is also the product of the alpha decay of ^{232}U and the electron capture decay of ^{228}Pa . The former of these two precursors of ^{228}Th is of particular interest to the techniques of measurement of uranium and thorium disequilibria as a radiochemical tracer. ^{232}U ($t_{1/2} = 72\text{ y}$) is a beta-stable alpha-emitter. The alpha spectrum of ^{232}U consists of three observable groups 5.318 MeV (68%), 5.261 MeV (32%) and 5.132 MeV (0.32%).

A fourth group with energy 4.998 MeV (0.01%) is deduced from gamma-ray measurements. The alpha spectrum of ^{228}Th ($t_{1/2} = 1.913\text{ y}$) consists of five energy groups: 5.421 MeV (71%), 5.338 MeV (28%), 5.208 MeV (0.4%), 5.173 MeV (0.2%), and 5.137 MeV (0.03%). The immediate daughter of ^{228}Th is ^{224}Ra ($t_{1/2} = 3.64\text{ d}$). It is an alpha-emitter with two prominent alpha particle groups: 5.684 MeV (94%) and 5.447 MeV (5.1%). There are three others of very low intensity: 5.159, 5.049 and 5.032 MeV. The second of the two main groups (5.447 MeV) is of particular importance in the analysis of alpha-spectra containing ^{228}Th groups because it appears hidden under the ^{228}Th alpha peak (Ivanovich 1992). The thorium series is illustrated in the following figure 1. 2.

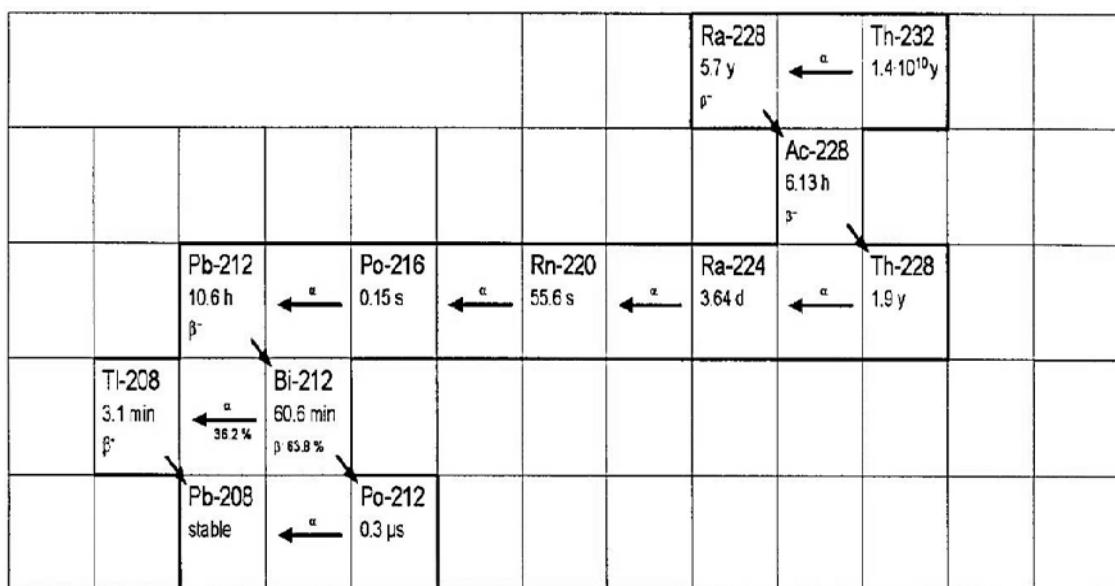


Figure 1. 2 Diagram schematic of thorium series (ISO 2005)

1.3.3 Uranium

Uranium was discovered by M. H. Klaproth in 1789 in Berlin, Germany, and isolated by E. M. Péligot in Paris, France in 1842. It appears as silvery metal. It is the most massive of the naturally occurring elements with intensity 18.8 g/cm³. It is the fourth element in the actinide series which is analogous to the lanthanide series of rare earth elements structurally and geochemically. Uranium occurs naturally in several minerals such as pitchblende, uraninite and carnotite. It is also found in phosphate rock and monazite sands. It can be prepared by reducing uranium halides with Group 1 or Group 2 metals, or by reducing uranium oxides with calcium or carbon at high temperatures. Uranium appears to be concentrated in the upper lithosphere, particularly in sialicigneous rocks and in late magmatic fluids. Uranium does not occur as a native element, nor does it form sulfides, tellurides, or arsenide. It behaves geochemically as a strongly oxyophile element (Lide 2002).

Uranium has a great importance, as it provides us with nuclear fuel. Although Uranium-235 has very low abundance, it is the only naturally occurring fissionable fuel and used in a breeder reactor. Uranium-238 can capture a neutron and undergo negative beta decay to become Plutonium-239. This synthetic, fissionable element can sustain a chain reaction, and the resultant heat is used to create steam to work turbines and generate electrical power. Uranium is the major material from which other synthetic Tran's uranium elements are made, and is also used to make isotopes for peaceful purposes, and to make nuclear weapons. The isotopes of uranium are shown in the following table 1. 4.

Table1. 4 Key isotopes of uranium (Lide 2002)

Nuclide	²³⁴ U	²³⁵ U	²³⁸ U
Atomic mass	234.04	235.04	238.05
Natural abundance	0.005%	0.720%	99.28%
Half-life time	2.47×10^5 y	7×10^8 y	4.51×10^9 y

1.3.3.1 Uranium-238

Uranium-238 series begins with the heaviest naturally occurring nuclide ^{238}U . It is the most abundant uranium isotope 99.2%; It has a half-life (45×10^9 y), it is one of the primordial nuclides of the crust. ^{238}U is an alpha-emitter, followed by a sequence of five successive alpha transitions. At the end of the series, the alpha-beta-beta sequence is repeated twice, and then the uranium series terminates on the lightest of the radiogenic lead isotopes ^{206}Pb . ^{238}U corresponding to a specific activity of 0.747 disintegrations per minute per microgram. The energy of the main group of alpha particles is 4.195 MeV (77% abundance). Conversion electrons of 48 KeV gamma ray have been observed indicating that the alpha decay is complex; another two alpha groups have been observed with respective energies of 4.147 MeV (23%) and 4.038 MeV (0.23%). The radioactive decay chain of ^{238}U is shown in the following figure 1. 3. Pure uranium emits no beta particles but energetic beta and gamma radiation are soon introduced by the ingrowths of the immediate daughters ^{234}Th and ^{234}Pa . This beta activity reaches equilibrium in undisturbed samples several months after the last purification of the uranium sample. ^{234}Th ($t_{1/2} = 24.1$ d) is a beta-emitter, the main group of beta particles in its spectrum has end-point energy of 191 keV, but there is another group complex 10³ keV energy. Gamma transitions with energies of 30, 60 and 93 keV have been reported.

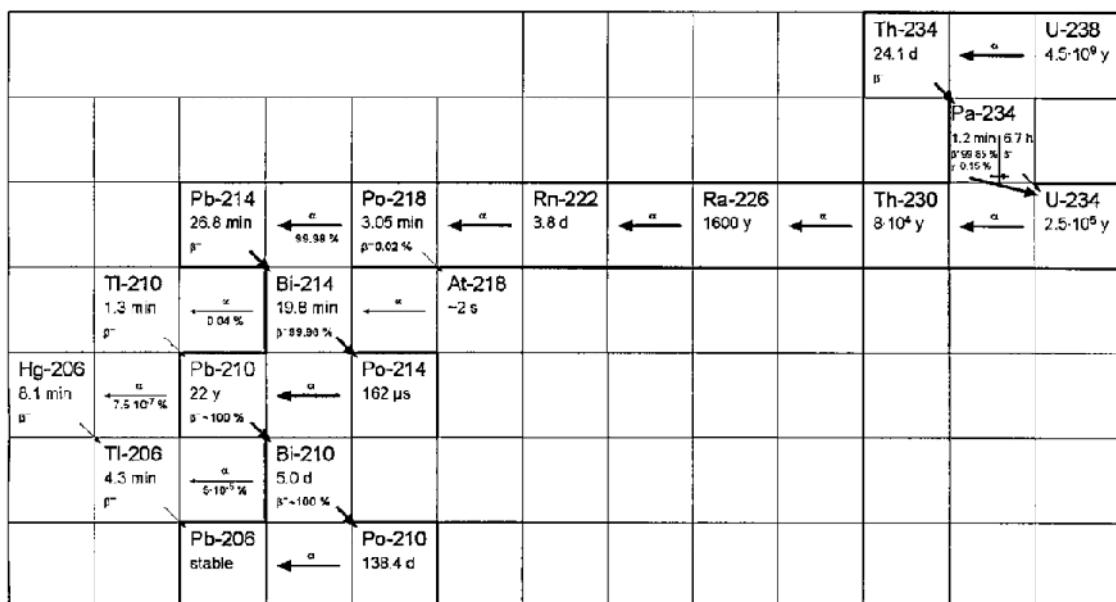


Figure 1. 3 Diagram schematic of ^{238}U series (ISO 2005)

In the beta decay of ^{234}Th , the principal daughter product is the 1.18 min ^{234}Pa . However, in 0.14% of its disintegrations an isomeric form of ^{234}Pa with ($t_{1/2} = 6.66$ h) is produced. The 1.18 min ^{234}Pa decays directly to the ground state of ^{234}U in 98% of its transitions. The continuous beta spectrum accompanying this decay has the high end-point energy of 2290 keV. The isomer ^{234}Pa has an extremely complex beta, gamma and conversion-electron spectrum. The fourth member of the uranium decay series is ^{234}U ($t_{1/2} = 2.48 \times 10^5$ a). It is a beta-stable alpha-emitter. The energy of the first group is 4.768 MeV (72%), and of the second group is 4.717 MeV (28%). An additional group with energy of 4.6 MeV (0.3%) has been observed and gamma-ray groups of 53 and 118 keV have been measured (Ivanovich 1992).

1.3.3.2 ^{226}Ra

Radium is a divalent alkaline-earth metal (Group IIA of the periodic table). It shares the chemical properties of beryllium, magnesium, calcium and strontium, and exhibits very strong geochemical coherence with barium. Radium is produced by the radioactive decay of uranium and thorium, and it occurs primarily in rocks bearing those elements, most notably the sialic (alkaline) igneous rocks, pegmatite and certain hydrothermal veins. Like the other elements in the group, radium forms a wide range of minerals, most of which have more familiar calcium, magnesium or barium analogues; the radium-bearing minerals are usually characterized by high melting points and very low solubility in water. Radium commonly replaces the other alkaline-earth metals didactically, substituting for calcium, magnesium and barium in common carbonate, sulfate and phosphate minerals.

There are four naturally-occurring radium isotopes, three of which have relatively short half-lives (^{223}Ra , 11.4 d), (^{224}Ra , 3.6 d) and (^{228}Ra , 5.75 y). The fourth and most abundant isotope, ^{226}Ra , has a half-life of 1.620 years, long enough to allow significant activity concentrations of radium to persist in geologically recent deposits without a supporting concentration of uranium or thorium. It is an alpha-emitter with four known alpha groups: 4.781 MeV (94%), 4.598 MeV (5.1%), 4.340 MeV (7×10^{-3} %) and 4.191 MeV (1×10^{-3} %). Several gammas are observed in the energy region between 186 and 610 keV. Thus, the radium concentration in certain post-Pleistocene marine deposits and in

some modern marine organisms is greater than the amount in equilibrium with the coexisting uranium. Except for some recent deposits, the distribution of radium is determined by the occurrence of uranium or thorium, modified somewhat by the chemical properties of radium itself. In Pleistocene and older rocks, the element is invariably found in association (and usually in radioactive equilibrium) with its parent nuclides (Majumdar 1990).

1.3.3.3 ^{222}Rn

Every person on earth is exposed to natural radiation. The most important source of radiation is radon gas ^{222}Rn . It was discovered in 1900 by Ernst Dorn, who named it Radium Emanation gas. It was later renamed neutron. The present name radon was first used in early 1920. ^{222}Rn is a daughter product of ^{226}Ra which in turn is derived from ^{238}U . We will explain ^{222}Rn in detail in the Part 1.5 (UNSCEAR 1977).

1.4 The Actinium Series

^{235}U makes up approximately 0.7% of natural uranium. This isotope has a half-life of 7.1×10^8 y, and is one of the primordial nuclides in the earth's crust. ^{235}U will undergo fission with slow neutrons and because it can sustain a chain fission reaction with the release of large amounts of energy, it is important as a nuclear fuel. ^{235}U yields ^{219}Rn as an intermediate daughter in the ^{235}U decay series figure 1. 4.

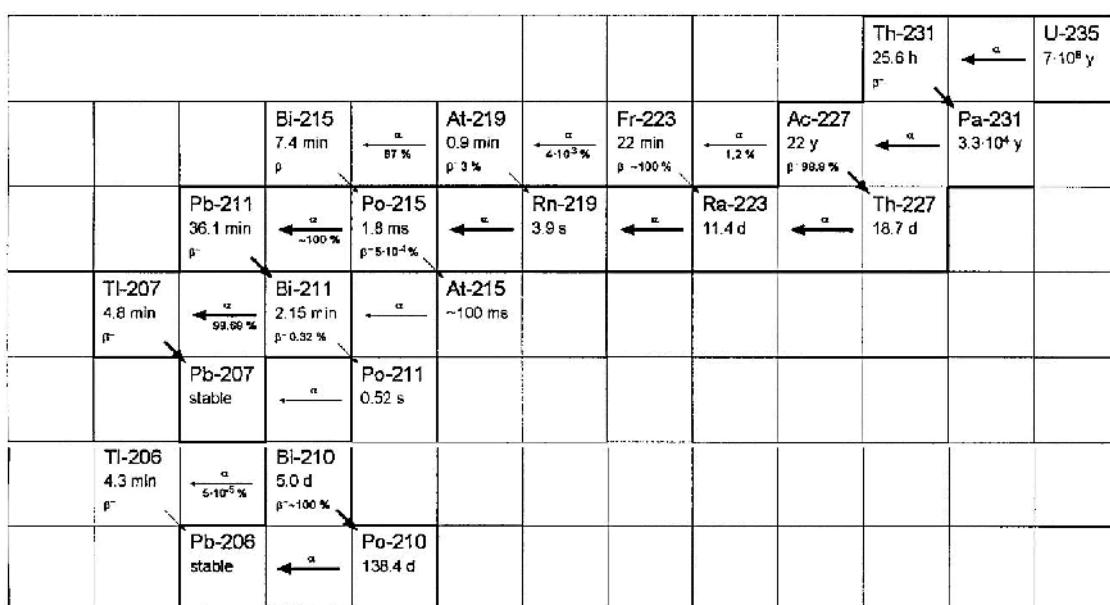


Figure 1. 4 Schematic diagram of actinium radioactive decay series (ISO 2005)

The actinium series begins in nature with its longest-lived nuclide ^{235}U , and ends with the stable lead isotope ^{207}Pb . ^{235}U It is conceivable that higher-mass nuclides in the actinium series like ^{239}Pu , ^{234}Cm , ^{234}Am , ^{247}Bk , etc. were also present when the elements were first formed, but of all the nuclides of this series above lead, only ^{235}U is sufficiently long-lived to have persisted throughout geologic time. Any sample of natural uranium, no matter what its source, contains ^{235}U in a constant amount relative to ^{238}U , namely 0.72 atom per cent (a notable exception are the samples from a fossil, natural ^{235}U fission reactor site at Oklo, Gabon). Thus 1 mg of pure natural uranium emits exactly 1501 alpha particles per minute. Of these 733.6 are emitted by ^{238}U , an equal number by ^{234}U in equilibrium with ^{238}U , and 33.7 by ^{235}U .

^{235}U is an alpha-emitter with a complex alpha spectrum and a correspondingly complex gamma spectrum. About ten alpha groups have been observed, all in the energy region between 4.1 and 4.6 MeV. Of these the two most prominent groups have energies of 4.391 MeV (57%) and 4.361 MeV (18%). The immediate decay product of ^{235}U is ^{231}Th ($t_{1/2} = 26.64$ h), it is a beta-emitter with a complicated decay scheme. The most energetic beta group has end-point energy of 300 keV and the total decay energy is 383 keV. The next nuclide in the actinium decay chain is ^{231}Pa ($t_{1/2} = 3.43 \times 10^4$ y). It is also an alpha-emitter and the longest-lived of the protactinium isotopes. The alpha spectrum of ^{231}Pa is complex with the highest-intensity alpha-group energies of 5.05 MeV (11%), 5.016 MeV (up to 20%), 4.999 MeV (25.4%), 4.938 MeV (22.8%), and 4.724 MeV (8.4%). Its daughter is ^{227}Ac ($t_{1/2} = 22$ y). Actinium-227 is a beta-emitter with end-point energy of about 45 keV (98.8%). Alpha-decay branching occurs with only 1.2% intensity. The most prominent alpha-group energies are 4.949 MeV (48.7%), 4.937 MeV (36.1%), 4.866 MeV (6.9%), and 4.849 MeV (5.5%) (Ivanovich 1992).

1.5 Radon and Thoron Decay Chains

All three of the natural decay chains ^{235}U , ^{232}Th and ^{238}U include isotopes of radon. ^{219}Rn or Actinon is a link in the ^{235}U chain. We will probably never encounter Actinon due to its scarcity and short half-life. ^{220}Rn or thoron is part of the ^{232}Th decay chain. We will sometimes encounter thoron in indoor air, particularly near radon entry points, and more often in soil gas. ^{222}Rn or familiar radon is part of the ^{238}U decay chain.

We will almost always be able to detect this gas water. The radon isotope is the first element in each of the decay chains that is not a metal. So it can escape any chemical compound its parent ^{222}Ra was in, and diffuse into the air. To focus on these inert gases, the ^{220}Rn and ^{222}Rn decay chains are shown in the following figure 1. 5.

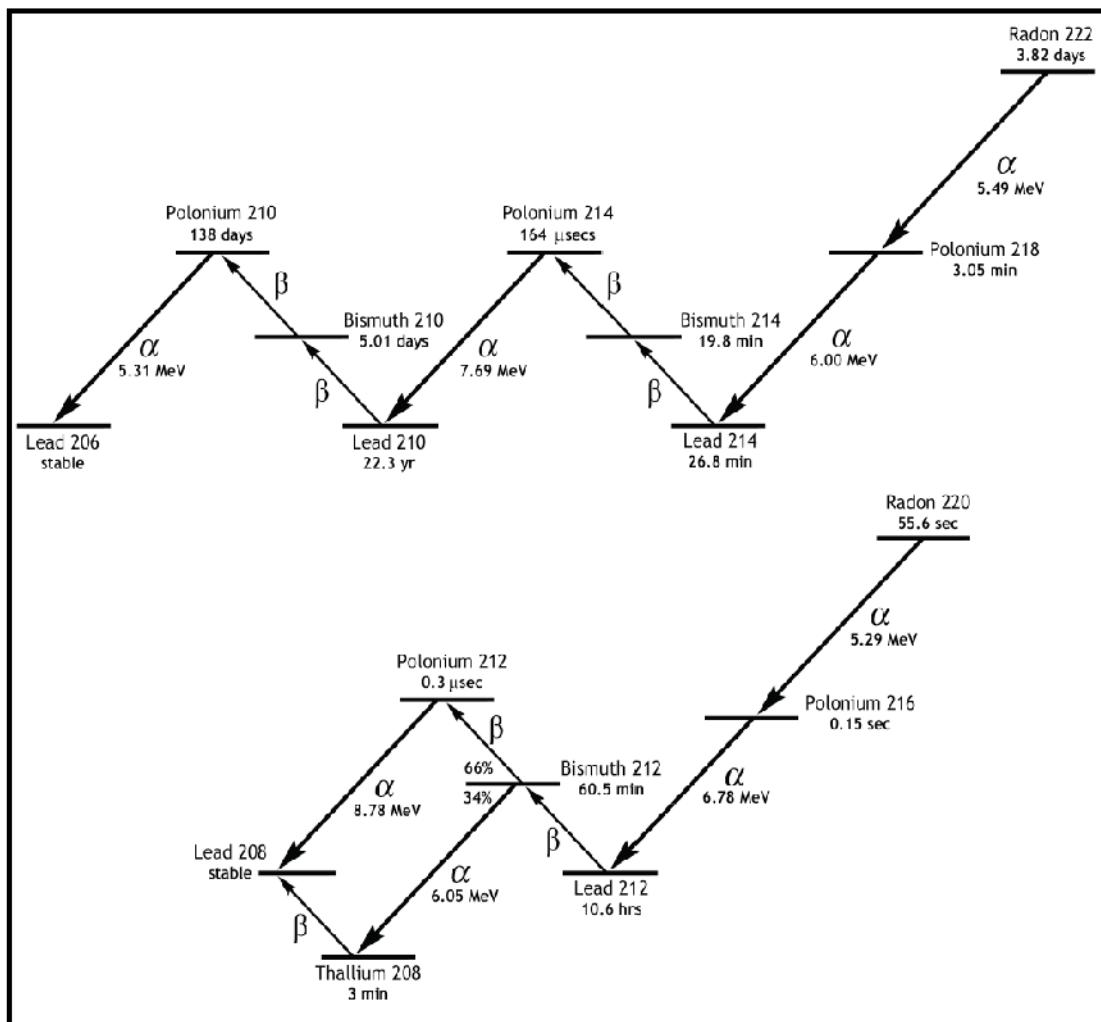


Figure 1. 5 ^{222}Rn and ^{220}Rn decay chains (RAD 2009)

Every nucleus of ^{222}Rn eventually decays through the sequence ^{218}Po , ^{214}Pb , ^{214}Bi , ^{214}Po and ^{210}Pb . With each transformation along this path the nucleus emits characteristic radiations: alpha, beta particles, gamma rays, or combinations of these. A particular radon nucleus may decay at any time, but it is most likely to decay between now and 8 days. When the radon nucleus decays, it releases an alpha particle with 5.49 MeV of energy,

and the nucleus transforms to ^{218}Po . This nucleus can never go back to ^{222}Rn again. Polonium atoms are metals and tend to stick to surfaces they come in contact with a dust particle in the air, or a wall, or the inside of the lung. ^{218}Po nuclei have a short half-life, only 3.05 minutes, which means that most of them will decay within 6 minutes of their formation. The average ^{218}Po nucleus lives for only 4.40 minutes before it decays (1.443 times the half-life gives the mean life).

Like ^{222}Rn , ^{218}Po emits an alpha particle when it decays, but with an energy of 6.00 MeV rather than radon's 5.49 MeV. When ^{218}Po decays, it transforms to ^{214}Pb , also a radioactive solid. But it has a half-life of 26.8 minutes, and it emits beta radiation rather than alpha radiation. When it decays, it becomes ^{214}Bi , also a radioactive solid and a beta emitter. It has a half-life of 19.8 minutes, and transforms to ^{214}Po when it decays. ^{214}Po is a bit different. It has a half-life of only 164 micro seconds, and it emits a 7.69 MeV alpha particle when it decays to become ^{210}Pb , which has a half-life of 22.3 years. This means that an average ^{210}Pb nucleus takes 1.443 times 22.3 years, or 32.2 years, to decay. Because of its long half-life, we usually ignore these nuclei as a factor in radon measurement. ^{210}Pb eventually undergoes beta decay to ^{210}Bi which quickly (5 days half-life) undergoes a further beta decay to ^{210}Po (138 days half-life) and decays with a 5.30 MeV alpha particle to stable ^{206}Pb . Similarly to ^{222}Rn every ^{220}Rn nucleus eventually decays through a sequence of 5 transformations to ^{208}Pb . The main distinction is the very different half-lives involved.

Thoron has a half-life of only 55.6 seconds. It emits a 6.29 MeV alpha particle and transforms to ^{216}Po , which in turn has only a 0.15 second half-life before emitting a 6.78 MeV alpha particle and transforming to ^{212}Pb . It hangs around for a long time, with a half-life of 10.6 hours. It transforms by beta decay to ^{212}Bi (60.6 min half-life). It has a 2:1 split, with two thirds transforming by beta decay to ^{212}Po and one third transforming by 6.05 MeV alpha decay to ^{208}Ti (3 minute half-life). The ^{212}Po decays immediately to ^{208}Pb , emitting an 8.78 MeV alpha particle in the process, while the ^{208}Ti undergoes a beta decay to the same destination ^{208}Pb (RAD 2009).

1.5.1 Radon

Radon exists in the earth's crust with varying concentration in different locations. It is believed that underlying soil is the main source of radon in the atmosphere of dwelling, office and public places (Khan 1993). Radon isotopes [^{219}Rn (Actinon), ^{220}Rn (Thoron) and ^{222}Rn (Radon)] are produced naturally within the grains of the bedrock of the earth crust, which contains the ores of uranium in secular equilibrium, (reached when the activity of each radioactive daughters is equal to the activity of radioactive parent).

Because of its short half-life (~4s), and because of very low abundance (^{235}U) of its forerunner, ^{219}Rn may be ignored entirely. But the half-life of ^{222}Rn (3.82 d) is much longer than that of ^{220}Rn (56 s). Therefore, there is a great probability for ^{220}Rn to decay in its cradle before finding its way out to the atmosphere. In consequence the entrance rate of ^{222}Rn to the environment is much greater than that of ^{220}Rn . So ^{220}Rn and its daughters are normally neglected in studying the "Radon problem" although their concentration is not trivial as that from ^{219}Rn (Abumurad 1997). It is widely accepted that the primary effect is not due to ^{222}Rn as such since inhaled ^{222}Rn is mostly expelled, but from the decay of alpha active nongaseous daughters of radon, ^{218}Po and ^{214}Po which is attached to aerosols. It can be lodged in lungs when inhaled. It has two immediate progeny, ^{214}Pb and ^{214}Bi decayed by relatively low energy beta-particle emission. Although beta particle may be energetic, they produce very low ionization density and so contribute little to biological hazard compared to alpha particles. The radiation from radon and its daughters cause a risk of lung cancer by inhalation of air with high radon and its daughter's concentration over a long period of time. The activity corresponds to about 25 year at radon daughter's activity of 400 Bq/m³. This activity corresponds to about 2×10^8 radon daughter atoms per m³ of air (Maged 1993, Maurice 1987). Over last decade; more emphasis has been placed on measuring ^{222}Rn levels in soil and attempting to correlate the resultant concentration to local geology. This is due to the fact that most of the radon in dwellings comes from the underground soil. The danger to the human health upon exposure to radon and its daughter's products is the main motivation behind the vast number of studies performed to find the concentration in our living environment. In the last two decades, there has been a great deal of awareness about the health risks from exposure to radon radioactive gas and its decay product. Figure 1. 6 shows the

sources of radioactive risk, the relative contributions sources: natural and man-made. It could be seen that natural sources provide about 82%, while the non-natural sources provide 18% of the average total dose that a human being commonly receives. The largest artificial sources are the medical. Most of the average dose comes from radon, which comes from the alpha decay of radium in the ground (Kamel 1998).

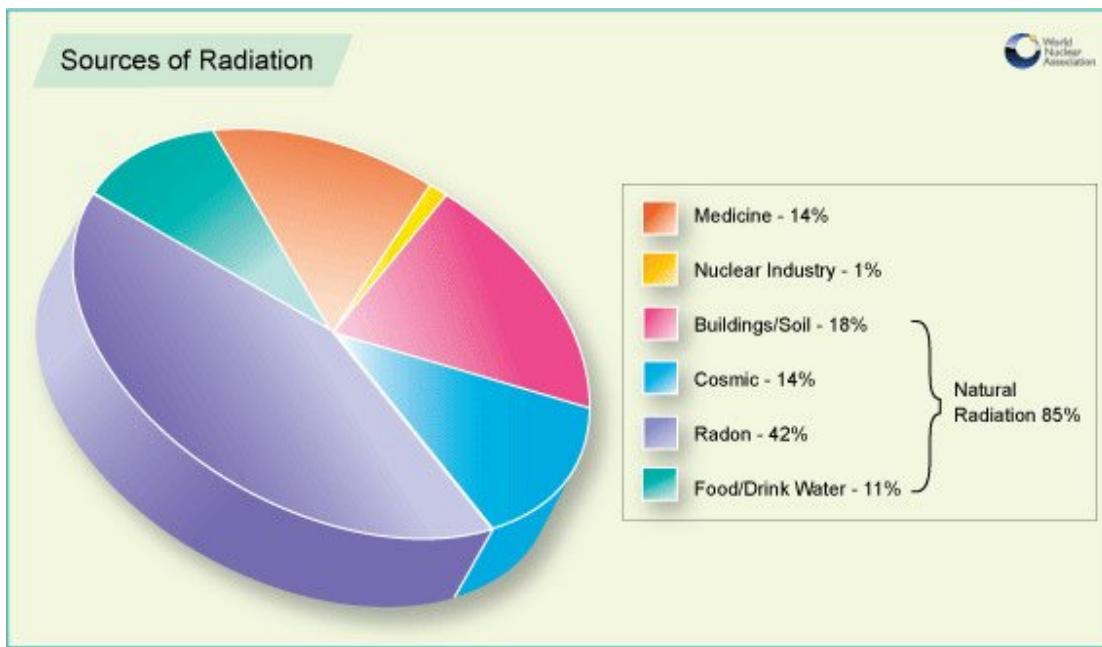


Figure 1. 6 The average annual doses to the world population from various sources
(WNA 2011)

1.5.2 Chemistry of Radon

^{222}Rn is colorless, odorless, tasteless, and is a noble gas. Therefore, all these characteristics made it difficult to detect it. Radon is widely dispersed in the environment. It is highly radioactive and decays by the emission of energetic alpha particles. It is the heaviest of the noble or chemically inert gases. It is heavier than air by 7.5 times. Its chemical inertness is due to its stable electronic configuration $[5s^2\ 5p^6\ 5d^{10}\ 6s^2\ 6p^6]$. Under normal condition; it does not react chemically with other substances. We must think of radon, not as a substance, but as isolated atoms whose transport is brought about by other gases (e.g.: CO_2 , CH_4 and N_2), in which they may diffuse being within a fluid

that may itself be moving. Radon is unique natural element in being a gas, noble and radioactive in all of its isotopes (Lide 2002).

1.5.3 Sources of Radon

1.5.3.1 Soil

Soil is a very complex material, and it varies in both physical and chemical properties to a very high degree. Soil may be considered a mixture of rock and mineral fragments and/or organic matter and liquid and/or gas. Soils and rocks rich in uranium are the main sources of radon to which people are exposed. A soil radon activity unnatural environmental condition is influenced by soil moisture content, barometric pressure variations and temperature and structure of soil. Loose sandy soil allows the maximum diffusion of radon gas, whereas frozen, compacted or clay soil inhibits its flow. The radon potential for a given region is likely to be the result of combination of properties of the soil and of the underlying rocks, such as the distribution of uranium and radium, porosity, permeability and moisture content of the soil, as well as metrological and seasonal variation. Radon moves in the ground either by diffusion or by transpiration mechanisms or by both. The dominate mechanism is determined by geological structure. Radon concentration depends on depth. The concentration increases with depth and may reach a maximum at depth of about 2 meter in the soil (Deepanjan 2000, Badr 1996, Abumurad 2001, Khan 1987, Jonsson 1987).

1.5.3.2 Building Materials

Building materials that are made from stone and sand contain uranium and radium and generate radon. Many of these materials, such as brick, wallboard or concrete are sufficiently porous to allow the radon to escape into the air. The diffusion of ^{222}Rn from building material is influenced by moisture content of the material, density, the presence of sealants, the material itself and the nature of the substances with which it is mixed (Douglas 1990).

1.5.3.3 Water Supplies

The ground water is the second most important potential source of atmospheric radon. Water supply can be a route of entry if there is a significant amount of radon in the ground water, and if the home water supply is derived directly from deep wells. Ground water in contact with crust rock penetrates into the pores and voids present in rocks and soils and dissolves radon that emanates into these spaces following radium decay. Radon is quite soluble in water. In equilibrium with radon gas at a partial pressure of one atmosphere, the solubility's range from 51 cm³ of radon per 100 cm³ of water at 0 °C to 13 cm³ of radon per 100 cm³ of water at 50 °C. Thus, the concentration of radon in underground water is not solubility limited even at high temperatures. When this water reaches the surface, most of the radon is released into the atmosphere, due to the reduction in the radon partial pressure, but the remaining small fraction can still correspond to a very large amount of radioactivity. This is one reason why very high concentration of radon can be found in some hot springs and well waters.

The concentration of radon in ground or well water depends strongly on the character of the host rock. (Hess 1982) measured radon contents of some two thousand samples from public and privately drilled wells in Maine and reported values ranging from 200 to 50,000 pCi/liter of water. The average water radon values obtained from 10 different granite bodies ranged from 1500 to 39,000 pCi/liter. Most surface waters have ²²²Rn concentrations less than 2 Bq/liter, and rarely do concentrations exceed 75 Bq/liter (Nazaroff 1987). On a nationwide basis (Cothern 1986) have estimated that the population-weighted-average radon concentration in drinking water is between 2 and 10 Bq/liter. The estimated airborne radon concentrations in houses using these waters, assuming a transfer coefficient of 1×10^{-4} (Hess 1985), would be in the range of 0.2 to 1Bq m⁻³. Because of the solubility of radon in water, very high levels of radon can occur even at the boiling point of water or higher temperatures, as reached in some hot springs. These spas have been used traditionally for therapeutic purposes, sometimes specifically with radon as the intended therapeutic agent. In studies of two Austrian spas, air activities in the periphery of the spa were 0.1 to 1.5 pCi/liter outdoors and 1 to 5 pCi/liter indoors, while in the bathhouse itself they reached as high as 3000 pCi/liter. In general, the health risks due to consumption of waters containing elevated concentration of radon are

insignificant. The dose to stomach due to the ingestion radon-rich water, for example, has been estimated to be less than 10 percent of that the lungs from breathing the accompanying air borne radon and its decay products (Cross 1985). As an interesting representation table 1. 5 shows the sources of global atmospheric radon and their contribution per years.

Table1. 5 Sources of global atmospheric ^{222}Rn sources (Cross 1985)

Sources	Million Ci per year
Emanation from soil	2000
Ground water (potential)	500
Emanation from oceans	30
Phosphate residues	3
Uranium mill tailings	2
Coal residues	0.02
Natural gas	0.01
Coal combustion	0.0009

➤ Radon Transport

Radon moves by two basic means, diffusion and forced flow. Diffusion inevitably occurs, even though its extent may be limited. Hence diffusive migration sets a lower limit on the transport of radon. Forced flow depends on pressure gradient, which may or may not be present in a given situation. Numerous hypothetical origins of such gradients have been proposed, but only occasionally are they dependably known to be active. In any such case diffusive effects superimposed on those of pressure gradients.

➤ Forced transport of radon in soil and rock

Pressure gradients can cause flow of the gas or liquid in interstitial space in the Earth, the ease of such flow being given by the hydraulic permeability P_{hy}

$$P_{hy} = \frac{\eta(dv/dt)}{A(dp/dx)}$$

Where η is the viscosity, $(dv/dt)/A$ the volume moved per unit time and per unit area, and dP/dx the pressure gradient. P_{hy} is in units of $(\text{length})^2$, usually either cm^2 or Darcys, where 1 Darcy = 10^{-8} cm^2 (Scheidiger 1960).

➤ Detection of vertical transport of radon in the earth

How does one learn whether transport is occurring? The procedure is to note what gradients exist in the ground in the absence of flow and then look for changes. Since in a uniform earth the primary reproducible gradients near the surface will be vertical, those are the gradients that are usually sought. The result is shown in figure 1. 7. The near surface zero radon concentration grows and by exponential decay approaches the concentration C at depth, with the characteristic distance $(D_t)^{1/2}$, which is 1.2 m for $D = 0.03 \text{ cm}^2 \text{ s}^{-1}$ (Fleischer 1984).

The radon lost to the atmosphere in each mean life is equivalent to an upward flux at the surface at a velocity $(D/t)^{1/2}$, which in this example is $2.5 \times 10^{-4} \text{ cm s}^{-1}$ (or 1.2 m/5.5 days). This is the velocity that any systematic up-flow (or down-flow) must exceed decisively in order to be easily recognized.

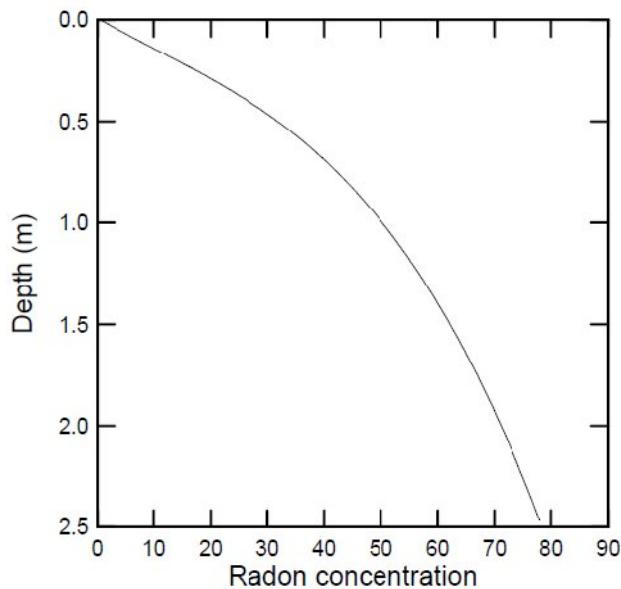


Figure 1. 7 Radon concentration ($10^2 \text{ cm}^{-2} \text{ month}^{-1}$) versus depth calculated for zero vertical flow

➤ **Mechanisms of forced transport in the earth**

What physical processes in the earth might produce pressure gradients and thereby affect radon flow? A number of observations of flow have been made and mechanistic models proposed. Although most of these processes no doubt occur at some times and places, it is difficult to prove for any single observation that in fact a particular mechanism was clearly responsible. Three main categories are gas emission, stresses, and fluid convection. Gases can be released by oil deposits (Fleischer 1984), and they can be generated and pressurized by hot regions such as volcanoes. Stress can be generated by the build-up of strains that precede earthquakes (Dobrovolsky 1979) and volcanic eruptions, and the stress gradients in turn can encourage fluid flow in the earth. Fluid convection could produce flows if there were sufficiently steep geothermal gradients and high enough perm abilities (Mogro 1977). Such flows could deliver signals from uranium deposits from greater depths than would allow detection of ore solely by diffusion of radon. Here again volcanic effects (in this case thermal) could reveal impending activity. A fourth contributor to pressure-induced flow is atmospheric pumping in the near surface soil by the pressure fluctuations that are associated with weather systems (Clements 1974).

1.5.4 Radon in Water

In a typical house, with typical water usage patterns, water borne radon concentration of 10,000 pCi/L will yield an average increase to indoor air concentrations of about 1 pCi/L. The 10,000:1 ratio, while not to be considered a hard rule, has been verified through theoretical models and empirical evidence (Hess 1990). In a house with a high radon in water content, air radon concentrations tend to rise dramatically with water usage, especially in the vicinity of the water-using appliance, but decline steadily after the water usage tails off (Henschel 1988). In most houses, water borne radon is a secondary source of indoor radon, far exceeded by soil gas infiltration. It is an exception, though not a rare one, that water borne radon is the major contributor to elevated radon in air. A home owner who has discovered elevated air concentrations, and whose house uses private well water, should test the water for radon content to assess the water's contribution to the air borne radon. This test ought to be done before any attempt to

mitigate soil gas infiltration, particularly if other wells in the area have been found to have radon (Henschel 1988).

Radon gas is, in physical terminology, soluble in water in the sense that the gas is transported by the water into the house. Its solubility in water is about ten times more than for oxygen gas. The gas follows the water from its source, where the surrounding bedrock and soil are producing the gas. As ^{226}Ra , the mother atom of the ^{222}Rn atom is soluble in water, the ^{226}Ra content in the bedrock and soil plays an important role. Water in rivers and reservoirs usually contain very little radon, because it escapes readily into the air. Homes, using surface water, usually do not have radon problem from the water supply. In cities where water processing in large municipal systems aerates the water allowing radon to escape, while the small water supply systems are often closed systems with short water transit times, that do not allow radon to be completely removed or decayed. Radon then escapes from the water into the indoor environment as people use the water for showers and washing (Abumurad 2001).

The rate of radon transfer from water to air increases with temperature, agitation, mixing, and surface area. In household water usage, showers, baths, dishwashers, laundries, and toilets all provide adequate aeration to release a high percentage of the water's radon content into household air (Prichard 1987). In principle, the radon will continue to be released from water as the aeration process continues, until a state of equilibrium develops.

➤ Radon as a Tracer for Ground Water Movement

Soil and rock typically contain significant concentrations of uranium and radium. Radon is continually being created in the ground so that groundwater often has high radon content. By contrast, open water contains very little dissolved radium. That, together with the proximity of the water surface, means that the background concentration of radon in sea and lake water far from land is very low. Radon then is an almost perfect tracer for measuring and monitoring the movement of groundwater into lake and sea water along the shore (Lane 2002, Burnett 1995). While open water monitoring often requires continuous and fast-response radon measurement at high

sensitivity, for groundwater in situ it is usually more convenient to use the Alpha GUARD.

➤ **Mitigation Strategies**

Two main strategies have emerged for the removal of radon from water. Both of these are applicable to point-of-entry (POE) water treatment in residences and small public water supplies. Granular Activated Carbon (GAC) attempts to filter the water by adsorbing radon on a charcoal bed that holds onto the radon until the radon decays. GAC systems can be effective and relatively inexpensive for residential use, but can create new problems. As the radon and its progeny decay in the GAC column, they give off gamma radiation. The gamma radiation may be a health concern to residents when the influent radon concentration is high, the GAC column is poorly shielded for high energy radiation, and the residents are likely to spend significant periods of time in the radiation field. Over time, a long lived decay product, lead-210, builds up in the column, which may pose disposal problems in systems with moderate to high radon concentrations in the influent. For that reason GAC is most often recommended for influent concentrations of up to around 5,000 pCi/L. GAC maintenance is simple and inexpensive, and the GAC bed has an expected service life of 5 to 10 years. (Henschel 1988, Lowry 1987, Rydell 1989) Aeration brings water into contact with a stream of low radon air, which strips the radon from the water, then exhausts the radon bearing air to the atmosphere. Aeration systems offer effective removal of radon without the buildup of gamma radiation or waste material, but tend to be substantially more expensive than GAC to install and maintain in a residential setting. Aeration can be used over the entire range of influent concentrations, though very high influent concentration may require a multiple stage system to reduce the effluent concentration to acceptable levels (Henschel 1988, Lowry 1987).

1.5.5 Health Effect and Risk

Inhalation of radon gas and its daughters will expose the lung tissue to short-lived alpha emitting radionuclide, which will increase the risk of lung cancer. Radon is also suspected to be a major factor increasing skin cancer, where alpha particles are suspected

to induce damage to epithelial cells due to deposition of radon on the skin. Kidney related diseases have also been observed in some people exposed to radon and this is due to the fact that kidney receives the highest dose, among the body organs, after radon being transferred from the lung to the kidney by blood. Inhaled radon may be transported to various organs after dissolving in blood. The concentration of radon in organs and the consequent dose both depend on the fat content of the organs, since radon is about 16 times more soluble in fat than in blood (As'ad 2004, Al-Sharif 2001).

Water borne radon leads to health risk by two pathways:

- Inhalation of radon and its decay products following the release of radon gas from water into household air.
- Direct ingestion of radon in drinking water.

The risk of lung cancer due to inhaled radon decay products has been well documented through the study of undergrounds mine workers. The cancer risk due to ingestion, primarily cancer of the stomach and digestive organs, has been estimated from studies of the movement of radon through the gas to intestinal tract and blood stream. Radon has not been linked to any disease other than cancer. The cancer risk from the inhalation pathway probably far exceeds that from the ingestion pathway (Crawford 1990, Federal 1991).

1.6 Exposure from Radiation Sources

The exposure to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. For most individuals, these natural back ground exposures are much more significant than the exposures caused by man-made sources. Exceptions that apply to certain individuals are some exposures caused by medical radiation procedures, through mishandling of radiation sources, in accidents allowing radionuclides to be released to the environment, and at some workplaces. In all cases, the natural back ground source form the baseline upon which all man-made exposures are added, and it is a common level against which these exposures may be compared.

Essentially there are two main contributors to the natural radiation exposure of man: charged and uncharged particles generated by high-energy particles of cosmic

origin incident on the earth's atmosphere, and radioactive nuclides originating either by interaction of cosmic-ray particles in the earth's atmosphere or being naturally present in the earth's crust everywhere in the environment, including the human body itself. From these sources dose to man arise from both external and internal exposure (Kaul 2005).

1.6.1 Exposures by Cosmic Radiation and Cosmogenic Radionuclides

Primary cosmic rays interact in the atmosphere producing a nucleonic cascade comprising protons, neutrons, pions and low-Z nuclei. The neutral pions decay to energetic photons. Through pair production, these generate a subsequent electromagnetic cascade of electrons and photons. Meanwhile, the charged pions decay to muons. The long free path of these muons and their relativistically expanded life time make them the dominant component of charged particle flux at ground level. In broad terms, at sea level, muons deliver just over 70% of the dose equivalent, electrons and photons about 15% and neutrons about 10%. Protons and charged pions contribute at the 1-2% level (Thorne 2003, UNSCEAR 2000).

1.6.2 Exposure by Terrestrial Radiation

Irradiation of the human body from external sources is mainly by gamma radiation from radionuclides in the ^{238}U , ^{232}Th series and from ^{40}K . These radionuclides are also present in the human body from ingestion and inhalation, and irradiate the various organs with alpha and beta particles, as well as gamma rays. Some other terrestrial radionuclides, including those of the ^{235}U series, ^{87}Rb , ^{138}La , ^{147}Sm , and ^{176}Lu exist in nature, but at such low levels that their contributions to the dose are small (UNSCEAR 2000). The ^{238}U series includes ^{222}Rn , which is of particular relevance to internal exposure by inhalation. ^{232}Th series includes ^{220}Rn , which is also of relevance to inhalation exposures. However because of its half-life (55 second), it tends to be less important than ^{222}Rn .

1.6.2.1 External Exposure from Terrestrial Gamma Radiation

➤ Outdoors

External exposure outdoors arise from terrestrial radionuclides present at trace levels in all soils depending on the types of rock from which the soils originate. Gamma-spectrometric measurements indicate that the three components of the external radiation field, i.e. from the gamma emitting radionuclides in the ^{238}U , ^{232}Th series and ^{40}K , make approximately equal contributions to the externally incident gamma radiation dose to individuals in typical situations both outdoors and indoors. Direct measurements of absorbed dose rates in air from terrestrial gamma radiation have been carried out in many countries of the world. Average values outdoors for the different countries surveyed range from 18 to 93 nGy/h. The population weighted average is 59 nGy/h (Thorne 2003, UNSCEAR 2000). The lowest values of the absorbed dose rate in air outdoor are in Cyprus, Iceland, Egypt, Netherlands, Brunei and United Kingdom, all less than 40 nGy/h, and higher values are in Australia, Malaysia and Portugal, all greater than 80 nGy/h. In addition to variations from place to place, the ambient back ground gamma dose rate in air at any specific location is not constant in time. It is subject to considerable fluctuation, in particular from the removal of ^{222}Rn progeny in air by rainfall, soil moisture and snow cover. There are small areas of markedly high absorbed dose rate in air throughout the world that are associated with monazite sand deposits, which have high levels of thorium, and radium deposited from waters flowing from hot springs (UNSCEAR 2000).

➤ Indoors

Indoor exposure to gamma rays is mainly determined by the materials of construction and their surrounding configuration indoors, and inherently greater than outdoor exposure if earth materials have been used. When the duration of occupancy is taken into account, indoor exposure becomes even more significant.

From surveys of absorbed dose rates in air inside dwellings the population-weighted average of the absorbed dose rate proved to be 84 nGy/h with national averages ranging from 20-200 nGy/h. The lowest values are in New Zealand, Iceland and the United

States, all below 40 nGy/h, which probably reflects the preponderance of wood-frame houses.

Overall UNSCEAR 2000 estimates a worldwide average effective dose rate of 0.48 mSv/a (0.41 mSv/a indoors and 0.07 mSv/a outdoors) (UNSCEAR 2000).

1.6.2.2 Internal Exposure from Terrestrial Radiation

Internal exposures arise from the intake of terrestrial radionuclides by inhalation and ingestion. Doses by inhalation result from the presence in air of dust particles containing radionuclide's of the ^{238}U and ^{232}Th decay chains. The dominant component of inhalation exposure is the short-lived decay products of radon, which is considered separately below. Doses by ingestion are mainly due to ^{40}K and to ^{238}U and ^{232}Th series radionuclides present in foods and drinking water. The dose rate from ^{40}K can be determined directly from external measurements in vivo of its concentration in the human body. The dose rate from uranium and thorium series radionuclides in the body is estimated either from measured activity concentrations after chemical analyses of tissues or from results of analyses of radionuclide contents of foods and drinking water, along with bioassay data and the knowledge of the metabolic and bio kinetic behavior of the radionuclides (UNSCEAR 2000).

➤ Internal Exposure due to Radon and Thoron

Inhalation of radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources. Inhalation of the short-lived decay products of ^{222}Rn , and to a lesser extent of the decay products of ^{220}Rn (Thoron), and their subsequent deposition along the walls of the various airways of the bronchia tree provide the main pathway for radiation exposure of the lungs.

The total global annual average of the effective dose from inhalation of ^{222}Rn and its decay products present in air, from dissolution of radon gas in blood and ingestion of radon gas with tap water is 1148 μSv with fractions of about 95% from inhalation outdoors and indoors and 5% from dissolved radon gas in blood and from ingestion of tap water. The annual effective dose from ^{220}Rn is 101 μSv with fractions of about 90% from inhalation and 10% from thoron dissolution in blood (UNSCEAR 1993). These estimates

of the global averages of the annual effective doses for radon only define the normal radon and thoron exposures. One may expect to find many large populations around the world in the order of 10^6 individuals, whose average exposures differ from the above global averages by a factor of more than 2, and up to a factor of more than 10 for many smaller populations in the order of 10^4 individuals (UNSCEAR 2000).

EXPERIMENTAL WORK

EXPERIMENTAL WORK

2 Materials and Method

2.1 Samples Collection and Preparation

Two hundred twenty water samples from different sites in Qena governorate, Egypt, have been collected and prepared, for measuring the activity concentrations of ^{222}Rn , ^{226}Ra , ^{232}Th and ^{40}K , by using two methods:

- Ionization Chamber "Alpha GUARD PQ2000PRO"
- Gamma ray spectrometry "NaI (Tl) Scintillation Counter"

These samples are classified as following:

- 109 ground water samples were collected from four areas in Qena:
 - ❖ 26 sample from Qift and Qus area. This area extended between the souths of Hagaza village in Qus area to the north of El-Salhia village.
 - ❖ 15 sample from Nakada area. This area extended between the souths of Nakada city to the south of El-Ashraf El-Baharia village.
 - ❖ 13 sample from Dishna area. This area extended between the begin of Qena-Safaga High way to Ezbit Ismail village in the north of Dishna area
 - ❖ 55 sample from Nagahammady and El-Waqf area. This area extended between the norths's of Dandara area to Naga-Zanaty in the north of Farshot area.
- 97 Drinking Tap water samples were collected from the city of Qena.
- 14 Different Kinds of Mineral water bottles were collected from Qena markets.

2.1.1 Ground Water Samples

2.1.1.1 ^{222}Rn Measurements

The collection of water sample requires particular care because ^{222}Rn is a short-lived gaseous nuclide that tends to escape from water during sampling. For ^{222}Rn activity concentrations measurements by using Alpha GUARD, the samples were collected from four areas in Qena governorate, east and west of the river Nile, as shown in the map figure 2. 1.

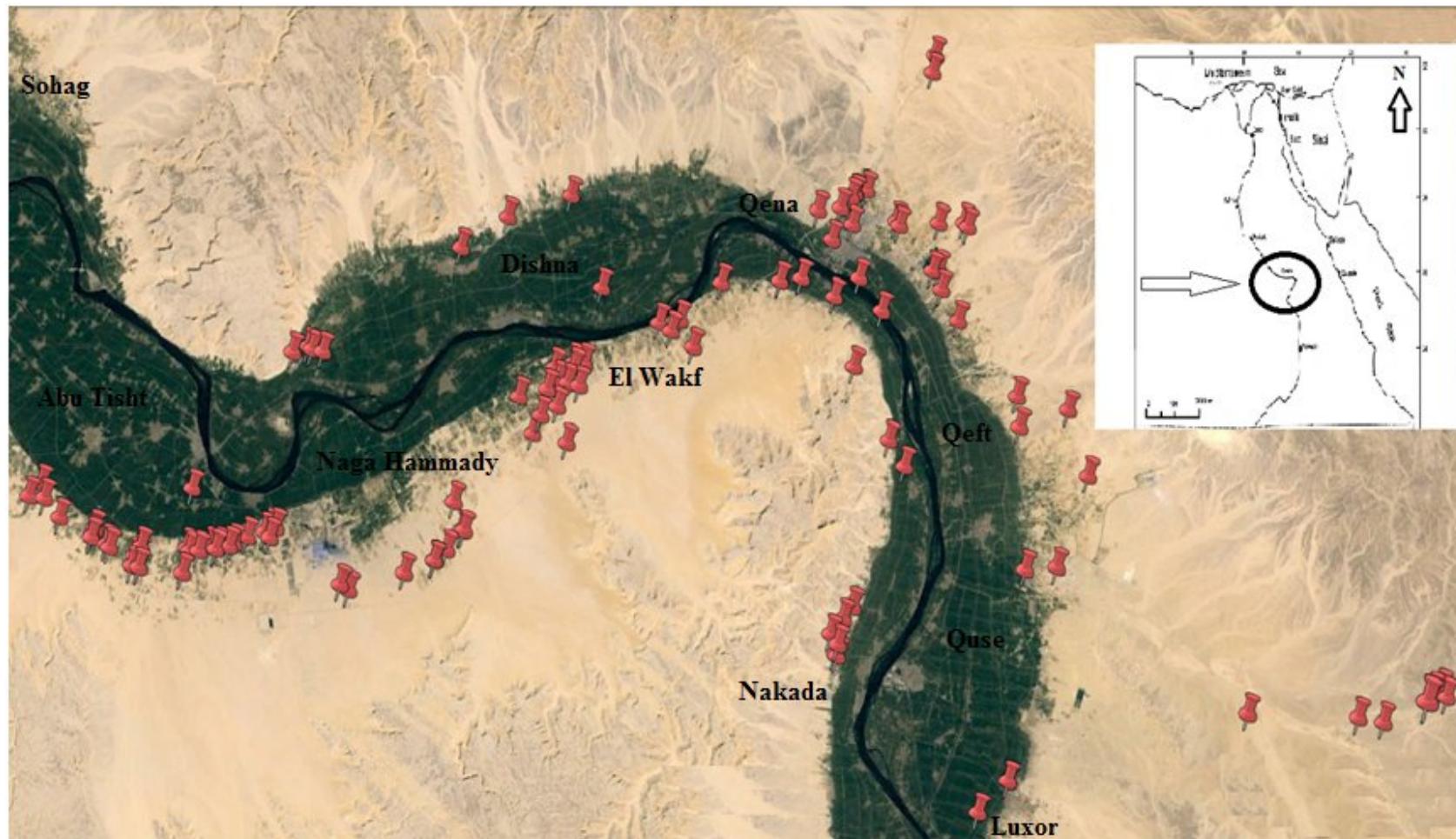


Figure 2. 1 Map of ground water sampling sites

At each site the well tap was opened, and the water was allowed to run for at least 20 minutes, in order to ensure that the water came directly from the well, and was not delayed in the well pipes. The taken samples were stored in bottles with 500 ml volume, that which completely filled, to avoid diffusion of radon from the water into an air pocket. During the process of samples transferring from the field to the laboratory, the samples were placed inside a closed box away from direct sunlight to avoid overheating. The samples were analyzed for ^{222}Rn as soon as possible after collection, to avoid uncertainties that may be introduced by radioactive decay of radon and losses from the sample container, the activity concentrations of ^{222}Rn were estimated using Expert software, for evaluating the alpha spectra figure 2. 2. All measurements were decay corrected to the time of sampling.

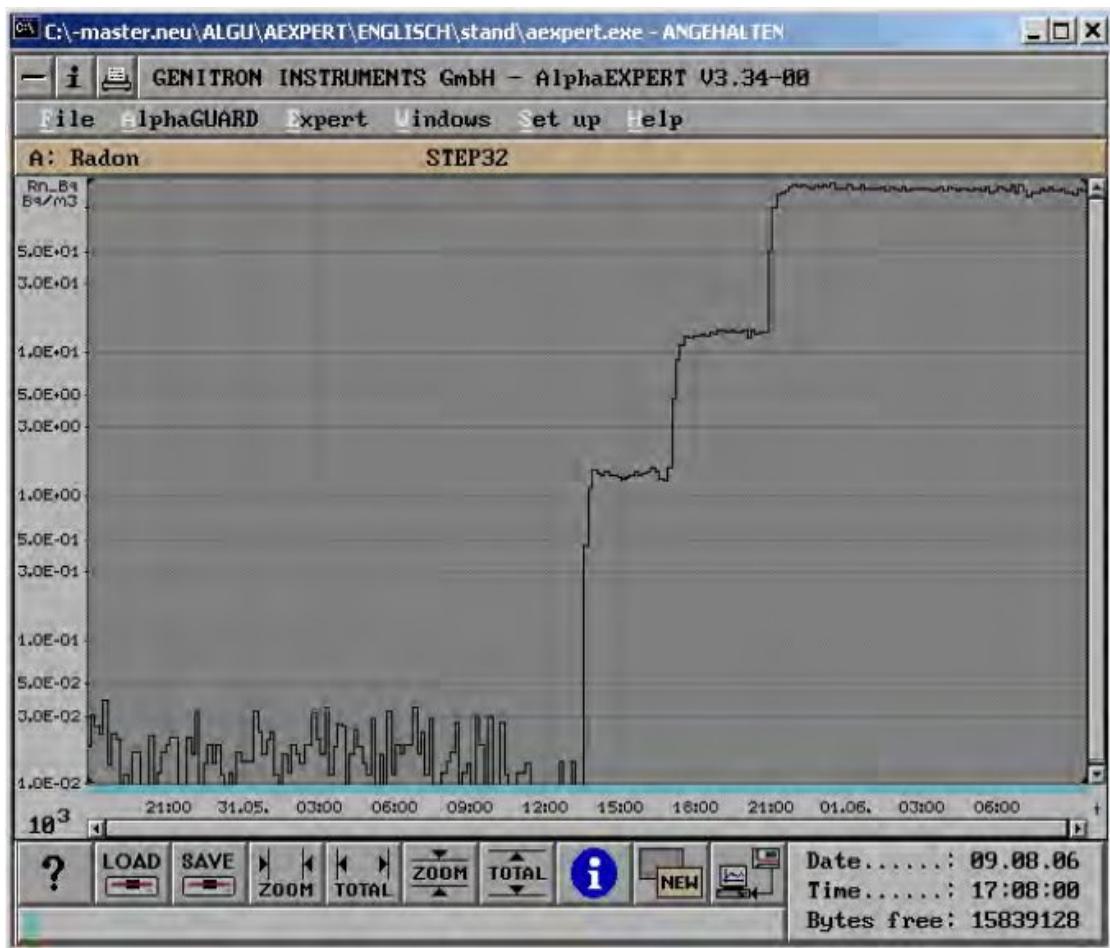


Figure 2. 2 Alpha GUARD spectrum for ^{222}Rn concentrations (Bq/m^3) with counting time

For ^{222}Rn activity concentrations measurements by using gamma spectroscopy, standard polyethylene Marinelli beakers (1.4 liters) were used as a sampling and measuring container. Before use, the containers were washed with dilute hydrochloric acid and rinsed with distilled water. Each beaker was filled up to brim and a tight cap was pressed on so that the air was completely removed from it. ^{222}Rn in water samples was determined at least four hours after sampling, using gamma spectrometry based on an NaI (Tl) detector, The ^{222}Rn activity concentration of water samples is assayed for 8 hour counting followed by analysis of gamma peaks from ^{214}Bi (609 keV) and ^{214}Pb (295, 352 keV) using GENEE 2000 software, for evaluating the gamma Spectra figure 2. 3.

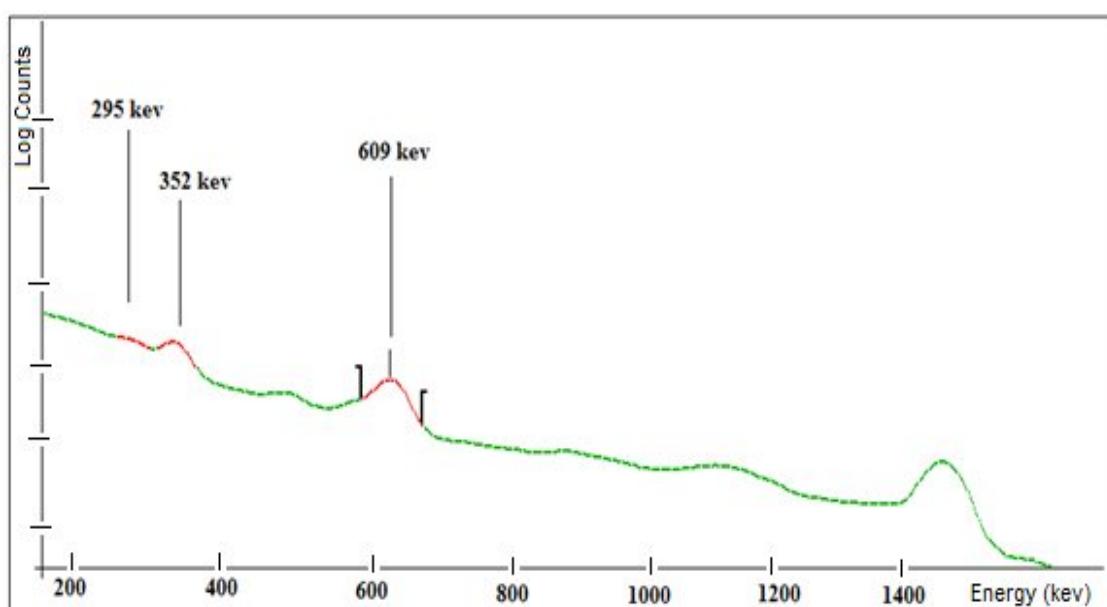


Figure 2. 3 Spectrum of ^{222}Rn measurements using gamma spectroscopy

2.1.1.2 Natural Radionuclides Measurements

The same samples have been measured for ^{222}Rn activity concentrations using gamma spectroscopy were stored for more than one month to reach secular equilibrium between ^{226}Ra , ^{232}Th and their daughter products before radiometric analysis of the natural radionuclides.

2.1.2 Drinking Water Samples (Tap and Mineral)

For tap water samples, the tap was opened, and the water was allowed to run for at least 20 minutes in order to ensure that the water not delayed in the pipes, the sample taken directly and slowly to the degassing vessel 500 ml in the AquaKIT measuring system, to avoid diffusion of radon from the water into the air. In the mineral water samples, every bottle was opened, and the sample was injected to degassing vessel. ^{222}Rn activity concentrations in drinking and mineral water samples were estimated at the moment of uses, so the measurements were not corrected for delay time.

2.2 Measuring Systems

2.2.1 Alpha GUARD

The Alpha GUARD is the center piece of a compact portable measuring system for the continuous determination of the ^{222}Rn Activity concentrations and climatic parameters; Temperature, Humidity and Air pressure. It can be operated mains independently as well as by mains power supply. This device uses the proven principle of the pulse ionization chamber. Alpha GUARD impresses by its high detection efficiency for ^{222}Rn , fast response to concentration gradients, as well as maintenance free long term operation, also in extreme air humidity. Alpha GUARD delivers reliable measuring values, and is insensitive to both vibrations and shock. The radon progeny measuring head TN-WL-02 is a professional sensor module for the recording of the air borne radon progeny concentration. The handy sensor unit is applicable for long term measurements as building examinations. The Pumping unit integrated in the measuring head sucks the air stream continuously. By this the radon progeny products are separated on a filter platelet. The alpha activity of the accumulated progeny products is measured by an alpha sensitive microchip which is located on the opposite of the filter platelet. Then the alpha activity is transferred as a TTL signal to the counter module of the connected Alpha GUARD PQ2000PRO. For routine graphical work up, evaluation, archiving and presentation of the measured data Alpha VEW-EXPERT is used as a comfortable, user-friendly (WINDOWS-similar) PC-software package. It includes an automatic transformation of the ^{222}Rn progeny concentration into the equilibrium equivalent ^{222}Rn concentration (Bq/m³). The Alpha GUARD monitoring system can be completed by

further external sensors for the continuous registration of ambient parameters, for example differential pressure and temperature. Figure 2. 4 shows Alpha GUARD center piece.



Figure 2. 4 Alpha GUARD (AquaKIT 1999)

2.2.1.1 Radon Detector

The radon detector of the Alpha GUARD is based on a design optimized pulse ionization chamber. In regular operation the measuring gas gets in diffusion mode via a large surface glass fiber filter into the ionization chamber. Through this filter only the gaseous ^{222}Rn passes, while the radon progeny products and dusty particles are prevented to enter the ionization chamber.

2.2.1.2 Ionization Chamber

The cylindrical ionization chamber of the Alpha GUARD as shown in figure 2. 5 has an active volume of 0.56 L. Its metallic interior has a potential of +750 V when the instrument is turned on. Along the longitudinal axis the stiff center electrode is located which lies on a potential of 0 V. The center electrode is connected with the signal input of the highly sensitive preamplifier unit. The worked up measuring signals of the preamplifier unit are transmitted to an electronic network for further digital processing.

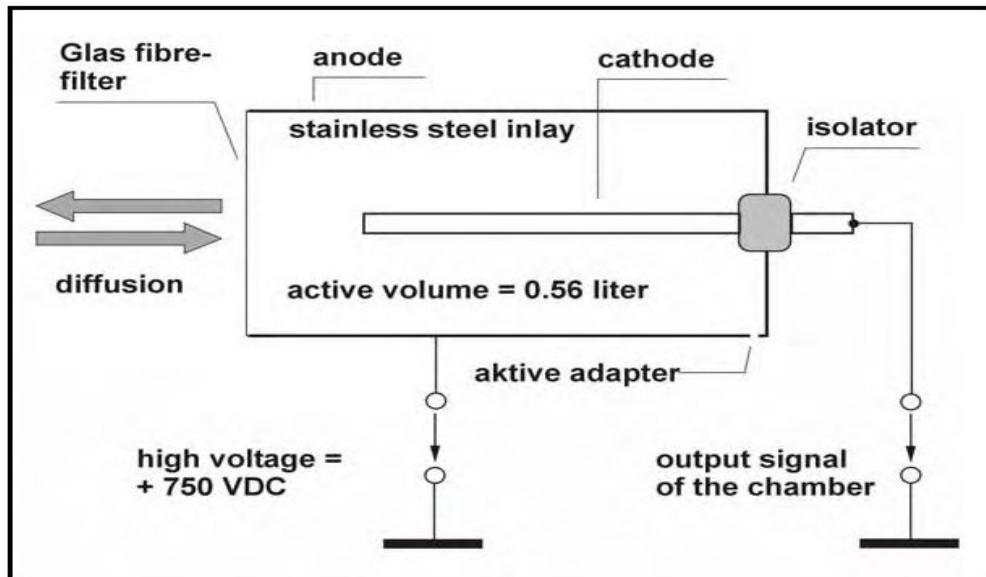


Figure 2. 5 Alpha GUARD ionization chamber (AquaKIT 1999)

2.2.1.3 Digital Signal Processing

For digital signal processing (DSP) there are three independent signal processing channels as shown in figure 2. 6. To each channel belongs a specific analog digital converter. This network concept allows analyzing the entering preamplifier signals simultaneously according to three different feature complexes.

Channel 1 is the spectrometric channel of the Alpha GUARD. Here, there is not only a signal characterization according to the pulse depth, but also a classification according to the pulse form. The result of this pulse analysis is a three-dimensional spectrum. Along the X-axis there is a classification of the pulse depth, (alpha energy). By the Y-coordinate the number of pulses per unit of time is described. The Z-coordinate stands for the classes of pulse forms. Because of this complex pulse characterization, a highly effective differentiation between real alpha events and different interference effects is possible (for example: micro phonic phenomena).

Signal processing via channel 2 is only effected with high ^{222}Rn concentrations. The dimensioning of the used band pass filter grants that the amplitude of the signal noise level is with high pulse densities direct proportional to the square root of the total ionization stream. By determined use of this relation, the current measurement in the Pico ampere range can be done with extremely high precision. Simultaneously by this a

regularly appearing source of errors is eliminated, the drift of the preamplifier offset, which results of the temperature sensitive FET-structure of the preamplifier.

Channel 3 stands for a classic direct current measurement. Its use is bound to the appearance of extremely high radon concentrations. Moreover it is a guarantee for a high fold back tightness of the measuring system. On the basis of these three signal characteristics six different analyzing algorithms are processed. Finally, via an optimized density procedure the real radon concentration is determined of them. By this any of the displayed radon values of Alpha GUARD is the final result of ca. 50.000.000 arithmetic operations. Only by use of latest semiconductor generation it is possible to keep the energy consumption of the Alpha GUARD down do the low level of 3 m ampere when handling such heaps of figures.

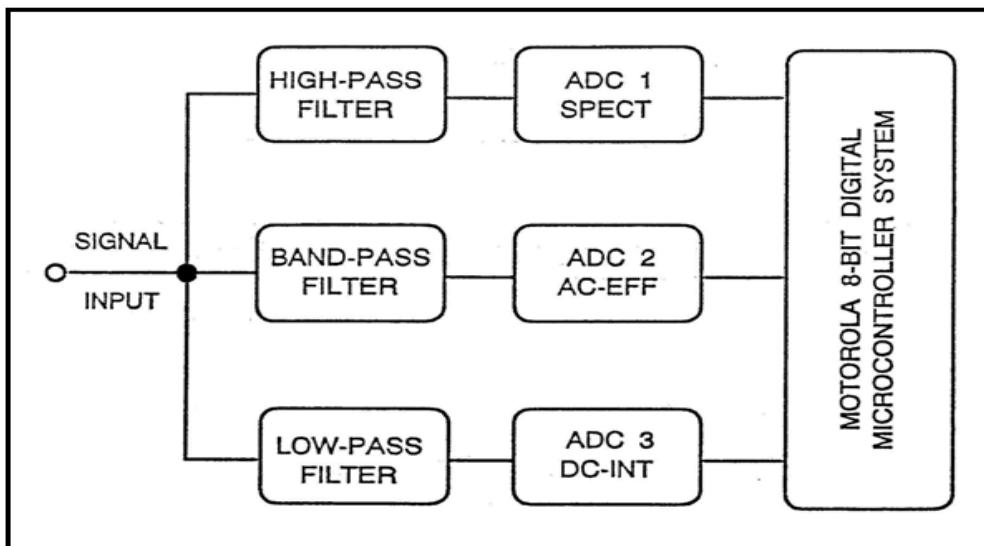


Figure 2. 6 Block diagram of digital signal processing (AquaKIT 1999)

2.2.1.4 AquaKIT

AquaKIT is an optional accessory to the ^{222}Rn monitoring system Alpha GUARD PQ2000PRO. In combination with the radon monitor and Alpha PUMP, electronic Pumping unit AquaKIT allows determining the ^{222}Rn concentration in water samples directly, and precisely, and stored in its memory in form of a concentration time series. The portable combination AquaKIT-Alpha PUMP-Alpha GUARD can be used for operation in the field. The batteries of Alpha GUARD and Alpha PUMP assist mains-independent operation of more than 12 hours.

The components of the AquaKIT measuring set-up and the use are described in the following:

- ❖ Degassing vessel
- ❖ Security vessel
- ❖ Plastic injections for sampling
- ❖ Mounting socket
- ❖ Connecting tubes
- ❖ Measuring cylinder
- ❖ Active coal filter cartridge

➤ **Degassing Vessel**

Degassing vessel is a gas washing vessel of DURAN modified for the particular measuring task. It takes up measuring samples of water. Out of this the radon is driven out of the sample. The standard set-up consists of:

- ❖ the cylindrical glass bulb with a volume of 200 ml
- ❖ the degassing cap with ascending tube, frit, three-way tap as well as three connecting sockets for tubes by interior quarter 4 mm The gas-tight connection between the two glass parts is assured via a cut clutch of the type NS 29/32.

➤ **Security Vessel**

Security vessel is coupled at the outlet side of the degassing vessel. All water drops shall deposit in it if they have got into the gas cycle during the degassing process. By this the stress of the water vapor is minimized for the radon monitor. Besides for the frit (which is not included) and a shortened ascending tube the security vessel is of the same layout as the degassing vessel.

➤ **Injection for Sample Taking**

As a particular device for sample taking four 100 ml plastic injections are enclosed. They allow a sufficiently exact portioning of the samples.

➤ **Mounting Socket**

Mounting socket assists a stable set-up of the measuring equipment. As shown in figure 2. 7 it fixes the degassing vessel, security vessel and the Alpha PUMP in a vertical

position. The mounting socket is a square shaped hard foam body with properly fitting sinking to take up the above mentioned parts of the measuring equipment.

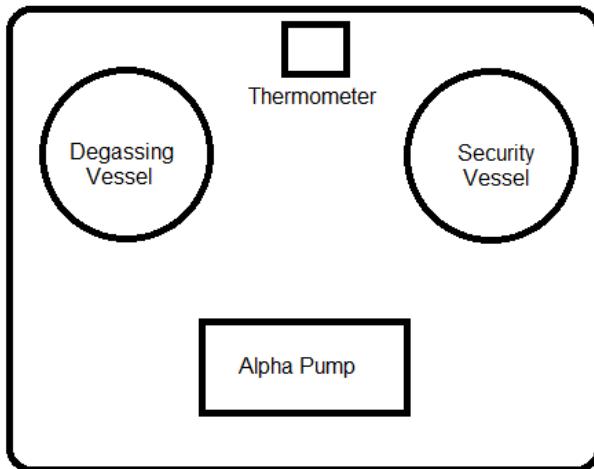


Figure 2. 7 Mounting socket (AquaKIT 1999)

➤ Connecting Tubes

Seven tube pieces of different lengths belong to the basic equipment. They serve as the way for the gas between degassing vessel, security vessel, Alpha PUMP and Alpha GUARD as well as the active coal filter cartridge. The plastic tubes are made of Tygon with an interior diameter of 4 mm. This plastic material has a particularly high resistance in diffusion for radon in contrary to the often used tube materials on silicon bases. The lengths of the different parts are 2x150 mm, 400 mm, 3x500 mm, and 600 mm.

The two 150 mm as well as the two 500 mm tube pieces are made with quick Fit quick-lock couplings (consisting of tube nipple and tube coupling). These couplings are equipped with internal valves which automatically close when the clutch is separated. By this an uncontrolled escape of radon resp. inflow of outer gas into the measurement set-up is prevented.

➤ Measuring Cylinder

The enclosed measuring cylinder (volume 250 ml) shall enable to exactly determine the volume of the sample after finalizing the ^{222}Rn measurement.

➤ Thermometer

The enclosed thermometer allows especially with precision measurements to exactly determine the temperature of the inspected water sample. The measuring range of the thermometer is from -10°C to +50°C.

➤ Active Coal Filter Cartridge

The active coal filter cartridge serves for the supply of radon-poor air. It is used with precision measurements for the exact determination of the intrinsic detector effect of the radon monitor, as well as for minimizing the radon level in the measurement set-up before sampling. The active coal filter cartridge consists of a plastic cylinder (Q/L: 75 mmx300 mm) with stable footings as well as tube nozzles at each front side.

Its interior is filled by Ca (1000 cm³) active coal. The diameter of the grain is 1.5 mm and the filling density is 0.4 g/cm³. The loading capacity of the used active coal is $\approx 1.25 \times 10^{-3} \text{ m}^3/\text{g}$. With this the active coal cartridge is equivalent to an air volume of approximately 500 L.

2.2.1.5 Alpha PUMP

Alpha PUMP is a battery operated electronically powered handy Pumping unit for gases. It can be gradually adjusted from 0, 03 to 1 Liter/minute. The electronics is optimized for minimal power consumption which grants a long life time of the storage battery. Alpha PUMP was developed as an accessory to the radon monitor Alpha GUARD and for the Alpha GUARD soil gas unit. It serves for sampling (once through filling of the ionization chamber), as well as for cycle operation when measuring the ²²²Rn emanation in barrels or vessels (storage vessel for radium containing substances and waste materials, exhalators etc.).

An internal aqua-stop filter prevents that possibly sucked in liquidity enters into the system. Thus the ionization chamber of the Alpha GUARD connected in series is protected from water break-in and thus makes expensive repairs superfluous. The PUMP is impermeable to gas and therefore also suited for calibration jobs with the Alpha GUARD. Figure 2. 8 show the alpha PUMP.

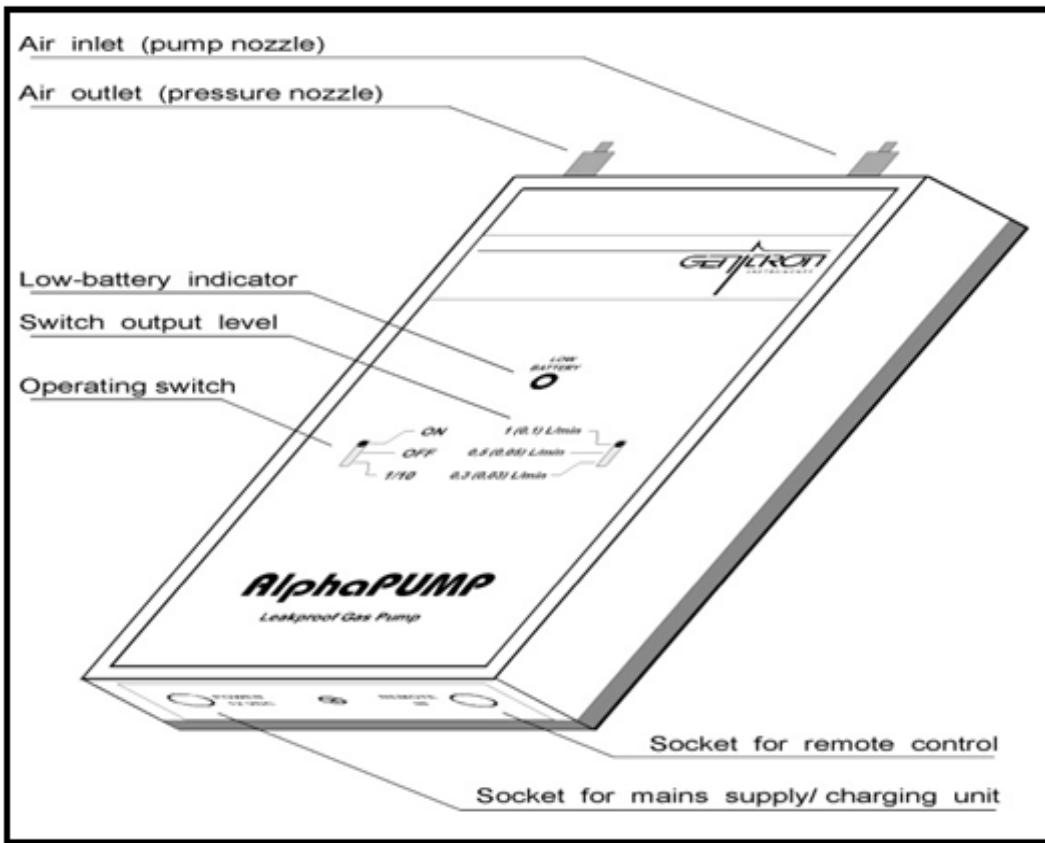


Figure 2. 8 Alpha PUMP (AquaKIT 1999)

➤ Alpha PUMP Operating Elements

On the front panel Alpha PUMP has two 3-step slide switches, and an indicator for the remaining battery capacity. On the upper narrow side there is an intake, and pressure nozzle for connecting the hose pipes. Connector sockets for mains operated power supply charging unit as well as for a remote control are located on the lower narrow side.

➤ Operating Switch

The left operating switch serves for switching the device on and off, and allows to select between continuous PUMP operation (switch position ON), and periodical PUMP operation (switch position 1/10). At periodical PUMP operation the respective Pumping performance is reduced to 1/10, by switching the PUMP in a regular cycle each time 2 seconds on and afterwards 18 seconds off. The PUMP is switched off when the switch is in the middle (OFF).

➤ Switch Output Level

The right hand slide switch (power amplifier switch) allows varying the output of the PUMP. In combination with the operating switch 6 different PUMP rates can be set in the range of 1.0 to 0.03 L/min as shown in the following table 2. 1.

Table 2. 1 Position power amplifier switch (L/min) (AquaKIT 1999)

Position Operating Switch	1 (0.1)	0.5 (0.05)	0.3 (0.03)
ON	1.0	0.5	0.3
1/10	0.1	0.05	0.03

➤ Nozzle (IN and OUT)

Intake and pressure stack are prepared with screw caps. To connect the hose pipes turn off the screw caps, and put in inverted position over the tubes. After mounting the tubes screw on screw caps on the respective nozzle and tighten only manually. The nozzles are prepared for tubes of 4 mm inside and 6 mm exterior diameter.

2.2.1.6 Set-up of the Measuring Equipment

For a well-functioning and stable set-up the degassing, security vessel and Alpha PUMP have to be set into the respective fittings of the mounting socket as shown in figure 2. 9. The tightness of the grounded clutches of degassing and security vessel should be granted via the grounded security clamps. The Alpha GUARD monitor is to be placed next to the mounting socket that the enclosed connecting tubes for creating a closed gas cycle can be used.

The tube connection should be done the following way:

1. The lower nozzle at the side of the top of the degassing vessel has to be connected with the lower nozzle of the top of the security vessel. This connection consists of the two 150 mm tube pieces with quick-lock clutch.
2. The lower nozzle at the side of the top of the security vessel has to be connected with the nozzle ‘IN’ of Alpha PUMP (tube length 400 mm).

3. The nozzle 'OUT' of Alpha PUMP has to be connected with the nozzle of the flow adapter at the right side of the Alpha GUARD (tube length 600 mm).
4. The nozzle of the active adapter at the rear of Alpha GUARD has to be connected with the upper side nozzle at the top of the degassing unit (tube length 500 mm - use tube without clutch element).

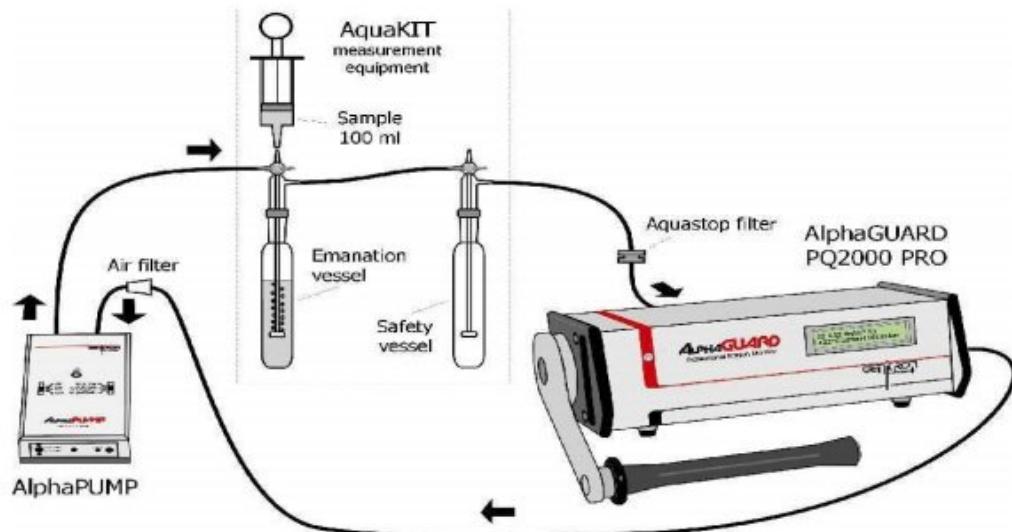


Figure 2. 9 Measuring set-up (AquaKIT 1999)

➤ Operation of the Three-Way Taps

The glass caps of degassing and security vessel are each equipped with a three-way tap. They allow both switching the open ways between sample and measuring operation as well as a safe handling when using the active coal filter cartridge.

➤ Positioning of Taps during Sample Injection

Figure 2. 10 shows the positioning of the three-way taps at the degassing and security vessel during the injection of the sample.

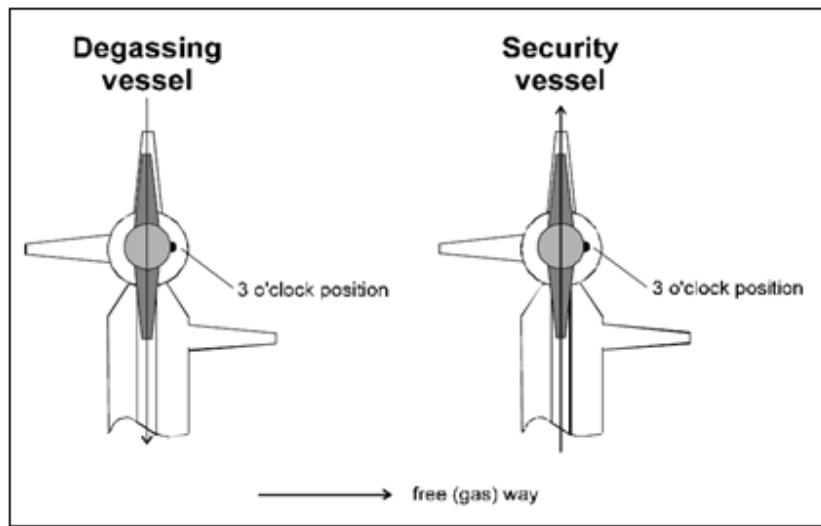


Figure 2. 10 Three-Way taps-position of the taps when the sample is injected
(AquaKIT 1999)

Notes:

- Deviations of the described tap operation scheme for injecting the sample could lead to pushing the liquidity into the gas way. This could lead to an undefined contamination of the measuring devices resulting in costly cleaning measures.
- The 3 o'clock position of the three-way tap at the security vessel during the injection of the sample assures the required pressure balance during this step.
- The three-way tap at the security vessel has immediately to be brought into the position for the measuring process after finishing the injection of the sample. By this uncontrolled escape of radon out of the measuring set-up is prevented.
- The three-way tap at the degassing unit must be switched to the position for measuring operation before separating the emptied plastic injection. By this uncontrolled escape of radon out of the measuring set-up is prevented.

➤ **Positioning of the Tap during Measurement**

Figure 2. 11 shows the positions of the three-way taps at the degassing and security vessel during the measurement.

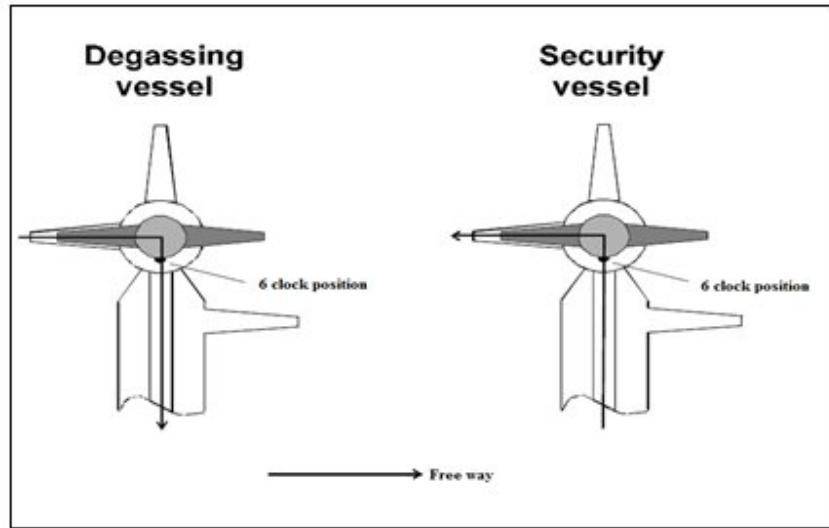


Figure 2. 11 Three-way taps positions of the taps during measurement (AquaKIT 1999)

2.2.1.7 Using the Active Coal Filter Cartridge

Normally for precision measurement it is necessary to diminish the radon level in the measuring set up before entering the sample. For this the supplied active coal filter cartridge (figure 2. 12) is bound into the gas cycle of the measuring set-up for some time. The radon in the measuring set-up is absorbed by the active coal and by this excluded of the gas cycle.

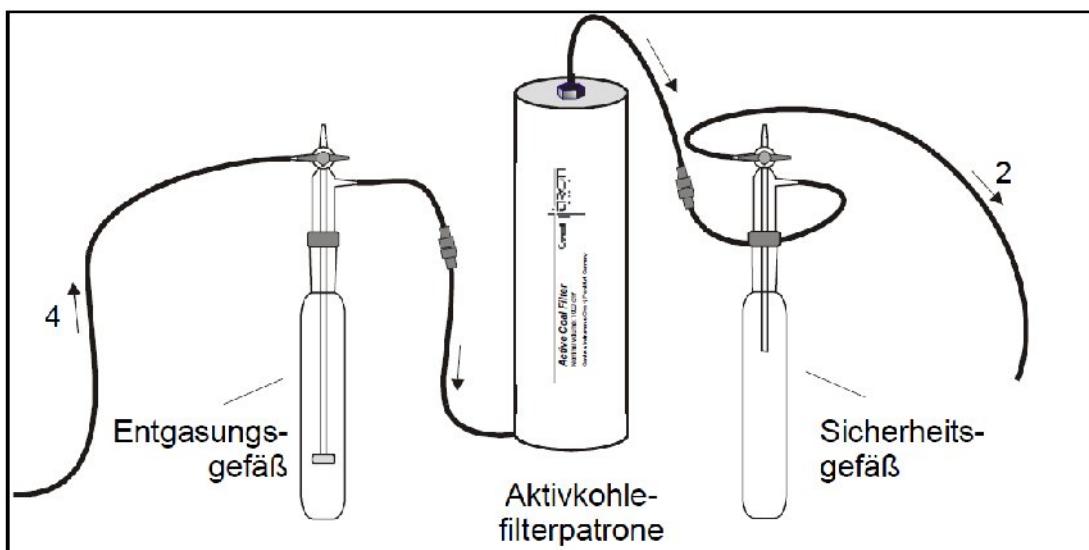


Figure 2. 12 Measuring set-up (section with enclosed active filter cartridge) (AquaKIT 1999)

The active coal filter cartridge shall be placed in the gas way between the lower connection nozzle of degassing and security vessel. For this the quick-lock clutch of its connecting tube is separated. Onto the active coal filter cartridge the two 500-mm tubes are placed which have at its ends a tube nipple resp. a tube clutch, with these clutch elements the filter cartridge is placed into the gas way between degassing and security vessel. The three-way taps are placed into 6 o'clock position and Alpha PUMP is switched on by switching the performance level switch to '1 L/min' and the operation mode switch to 'ON'. After the required "zero level" is reached Alpha PUMP is switched off, the active coal filter cartridge taken off the gas way and the tube clutch in the gas way between degassing and security vessel is reconnected.

2.2.1.8 General Aspects of Measuring

The main condition for correctness and exactness of the measurement is qualified sampling. In particularly the ^{222}Rn losses on the way between sampling and the measurement have to be minimized. For the actual procedure the following aspects which are signified by a general conflict of targets have to be taken into account:

1. Exactness and correctness of measurement (quality aspect)
2. Sample throughput / rapidity of analysis (quantity aspect)

➤ Alternatives in Sampling

In the following the alternatives for sampling with AquaKIT are described. There is a direct and multistage transfer of samples which have to be differed. The direct transfer of samples emphasizes the quality aspect. The multistage procedure stands for a significant faster throughput of samples where the therefore caused elevation of the error rate can be neglected for quick measurements.

➤ Direct Transfer of Samples

For the direct transfer of samples the supplied 100 ml plastic injections can be disposed of. E.g. 100 ml of the liquidity to be measured are taken up with the injection and afterwards directly injected into the upper nozzle of the degassing unit. Afterwards the measurement operation is started. But we take care that the correct position of the three way taps is kept at the degassing and security vessel during sampling.

➤ Multistage Sample Transfer

In order to take as many samples as possible and to safely store them until the measurement in the laboratory also the other lower parts of the glass vessels supplied may be used (2x100 and 2x500 ml). For this the vessels shall be filled with overflowing water samples and later be closed with the enclosed glass stoppers and security clamps. For the measurement of the samples the following procedure shall be taken:

❖ 100 ml Lower Glass Vessel

Take off the glass stopper and immediately enter the degassing cap. Afterwards reduce the quantity of the sample in the degassing vessel to approximately 100 ml with the plastic injection placed on the upper filler socket. The three-way taps are set to 3 o'clock at the degassing vessel and to 9 o'clock at the security vessel (for a pressure balance). Taking off the closing stopper of the sample storage vessel and putting up the degassing cap must be done without interruption in order to minimize the escape of radon of the water sample and the transition into the surrounding air. The three way taps of degassing and security vessels are switched on to 3 o'clock position when the degassing cap is placed (pressure balance). After the end of the ^{222}Rn measurement the exact sample volume has to be determined with the measuring cylinder.

❖ 500 ml Lower Glass Parts

About the 500 ml vessel we take off the glass stopper and tear the liquidity from the ground of the bottle with the 100 ml plastic injection. Then we inject the part of the sample taken up into the degassing vessel. Removing the part of the sample has to be done immediately after taking off the stopper in order to minimize radon escape of the sample into the surrounding air. The three-way taps of degassing and security vessel shall be in 3 o'clock position when the sample is placed (pressure balance).

Further Samples Can also kept for a short time in the supplied four plastic injections. The storage time of the samples in the plastic injections is determined by the characteristics of absorption and the permeability towards radon. Thus on one hand the plastic takes up radon of the water sample and leads it to the surrounding air. On the other hand the radon taken up of the plastic parts can diffuse again in a following measuring sample. By these processes the measuring results can be tampered when they remain too long in the plastic injections. The plastic injections in which samples with high ^{222}Rn

concatenations tents have been stored can only be reused after one-day heating in a shelf drier at 60 °C.

2.2.1.9 Determinations of Radon Activity Concentrations

➤ General Basics of the Calculation

Determination of the radon activity concentration in the water samples is based on the ^{222}Rn activity concentration indicated on the radon monitor. E.g. this measuring value is not yet the ^{222}Rn activity concentration in the measured sample because the radon driven out has been diluted by the air within the measurement set-up and a small part of the radon remains diluted in the watery phase. For quantifying the dilution effect the exact interior volume in the measurement set-up (V_{system}) is required. The quantity of radon remaining in the sample can be determined by the introduction of the distributing coefficient K, which describes the temperature dependent quantity of the sample which remains chemically dissolved. Thus the general approach as presented in the followed equation for the determination of the ^{222}Rn concentration in the measured water sample is valid:

$$C_{\text{water}} = \frac{C_{\text{air}} \times \left(\frac{V_{\text{system}} - V_{\text{sample}}}{V_{\text{sample}}} + K \right) - C_0}{1000} \quad \text{Eq.1}$$

Where $C_{\text{water}} = ^{222}\text{Rn}$ (Bq/l) in water sample, $C_{\text{air}} =$ the Indicated ^{222}Rn (Bq/m³) by Alpha GUARD, $C_0 = ^{222}\text{Rn}$ (Bq/m³) in the measuring set-up before sampling (zero level), $V_{\text{system}} =$ interior volume (ml) of the measurement set-up, $V_{\text{sample}} =$ volume (ml) of the water sample, K = Radon distribution coefficient.

➤ Marginal Conditions

The exactness and correctness of the Alpha GUARD indicated values and thus also for the determined ^{222}Rn activity concentration of the water sample depends on the following marginal conditions:

- ❖ Relation of volume sample/measurement set-up
- ❖ Tightness of measurement set-up
- ❖ Temperature of sample

- ❖ Radon level in the set-up before sampling
- ❖ Background (intrinsic effect) of Alpha GUARD

➤ Relation of Volume Sample/Measurement set-up

Determination of the relation of sample and measurement set-up is based on the exact knowledge of the interior volume of the set-up. The interior volume of the set-up results from the sum of the interior volumes of the components integrated into the set-up as shown in the following table 2. 2. It is differed between the measurements set up for the execution of so-called quick measurements and precision measurements:

Table 2. 2 Volumes of AquaKIT system components (ml), and calculated total volumes of measurement se-tup (AquaKIT 1999)

Quick Measurement	Volume	Precision Measurement	Volume
Ionization Chamber of Alpha GUARD	680	Ionization Chamber of Alpha GUARD	680
Alpha PUMP	18	Alpha PUMP	18
100 ml Degassing Vessel	190	500 ml Degassing Vessel	618
Security Vessel	191	Security Vessel	191
Tube Connection (1.8 m)	23	Tube Connection (1.8 m)	23
Total Volume	1102	Total Volume	1530
Error in the Total Volume	±1%.	Error in the Total Volume	±1%.

➤ Tightness of the Measurement Set-up

The components combined in AquaKIT and the layout of the gas ways are targeted on the best available minimization of radon losses by leakage and diffusion. The fulfillment of this goal can be proofed with the results of respective tightness tests. Thus the user can be assured practically a measurement setup free of leakage if the set-up was done correctly. For quick measurements, the radon losses in consequence of the relatively slow radon diffusion in and through the tube walls can be neglected.

➤ K Factor

According to Henry's law of dilute solutions, equilibrium will occur when the ^{222}Rn concentration in water and the ^{222}Rn concentration in the air were reaching to a fixed ratio for a certain temperature. This ratio derivable from the Henry's law constant for radon dissolved in water is known as the distribution coefficient, partition coefficient or Ostwald coefficient, and given by the following equation:

$$K = \frac{\text{Concentration in the liquiedphase}}{\text{Concentration in the gas phase}} \quad \dots \dots \dots \text{Eq.2}$$

For radon in water at 20° C the distribution coefficient is about 0.25, so radon will continue to release from the water until the water concentration drops to about 25% of the air concentration. Remember that as the radon leaves the water into the air it raises the air concentration and lowers the water concentration. At lower temperatures the distribution coefficient increases, rising to 0.51 at 0°C. At higher temperatures the distribution coefficient decreases, to about 0.11 at 100°C. Figure 2. 13 shows the temperature dependency of the diffusion coefficient K. An empirical expression for the distribution coefficient of radon in water as a function of temperature can be found in Weigel formula (Weigel 1978):

$$K = 0.105 + 0.405 \times e^{-0.0502T} \quad \dots \dots \dots \text{Eq. 3}$$

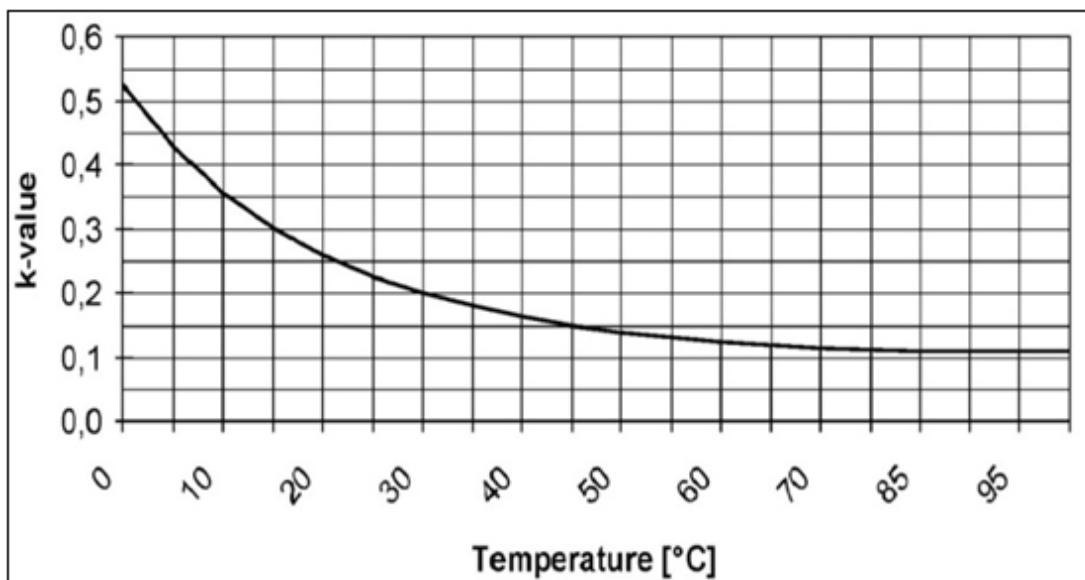


Figure 2. 13 Temperature dependency of the diffusion coefficient K (Clever 1985)

➤ Radon Level in the Measurement Setup before Injecting the Sample

Applying the ^{222}Rn activity concentrations equation it is strictly speaking based on the assumption that the air inside the measurement setup is free of radon. In general, however this will not be the case if the measurement set-up has been flushed with room air before the start of the measurement. In most cases it is assumed that the ^{222}Rn activity concentration in the room air is below 100 Bq/m³. “Zero levels” in this order can be neglected with quick measurements as long as for the samples ^{222}Rn Activity concentrations above several Bq/L resp. of several k Bq/m³ can be expected. If however for the samples lower ^{222}Rn activity concentrations are to be expected or significantly higher radon air concentrations have to be assumed it is necessary to measure the “zero level” of the measurement set-up before injecting the sample.

For this a 10-minute measuring time is sufficient by which the air enclosed in the “empty” measurement set-up is rotated by switching on Alpha PUMP, conducted through the ionization chamber of Alpha GUARD and measured. In the mean value of the adjacent measuring series the current “zero level” of the measurement set-up is reflected. E.g. this offset has to be subtracted of the determined ^{222}Rn activity concentration for the subsequent sampling. With the analysis of the measuring series for the determination of the “zero level” it should be abstained from the measuring value of the 1-minute cycle which follows immediately after switching on Alpha GUARD as long as it cannot be assured that already at the beginning of the measuring series the radon activity concentration of the measurement set-up is reflected in the ionization chamber of Alpha GUARD.

The variation of the single 1-minute values for ^{222}Rn Activity concentrations in the range below 300 Bq/m³ are of statistic nature and determined by the accidental diffusion of the appearing alpha pulses in the 1-minute cycle. Applying the precision method and here particularly for the lowering of the detection limit before sampling the radon resting in the measurement set-up shall be removed.

For this the delivered active coal filter cartridge shall be included into the gas cycle. In the gas cycle closed to the exterior the air shall be rotated with Alpha PUMP as long as the ^{222}Rn level has reached <5 Bq/m³.

➤ Procedures for Quick Measurements

The following description contains the steps for executing quick measurements in a systematic order.

Measuring steps

1. Set up the equipment consisting of AquaKIT, Alpha PUMP and Alpha GUARD as described in the figure 2. 9.
2. Switch on the Alpha GUARD monitor and select measuring mode "10 min FLOW" (setting is done via the Alpha GUARD menu or by using Alpha EXPERT-VIEW software).
3. Bring the three-way taps at degassing and security vessel into the 3 o'clock position foreseen for sampling.
4. Dock the plastic injection with the water sample which is to be measured to the vertical connecting socket of the degassing vessel.
5. Empty the plastic injection slowly into the degassing vessel.
6. Bring the three-way taps of the degassing and security vessel immediately into the 6 o'clock position for measuring mode. By this the gas cycle is closed.
7. Remove the plastic injection of the vertical connecting socket of the degassing vessel.
8. Set the Alpha PUMP performance level switch to a flow rate of 0.3 L/min.
9. Bring the operation mode switch of Alpha PUMP in position ON and start of sampling measurement.
10. After 10 minute rotating operation switch the operation mode of Alpha PUMP to position 'OFF'. Alpha GUARD remains switched on for another 20 min, e.g. the radon measurement is continued.
11. Repeat this cycle three times in order to obtain a better precision (Elzbieta 2004). Which ^{222}Rn values up to the maximum value, then it down again.
12. Remove the measured water sample of the degassing unit and reassemble the equipment. Disconnect the tube from the active adapter at the rear of Alpha GUARD.

13. Set the Alpha PUMP performance level switch to a flow rate of 1 L/min and the operation mode switch to position ‘ON’ (rinsing of measurement setup with room air).

Rinsing of the measurement setup is continued until radon values are reached in the range of room air concentrations. Afterwards the next measurement procedure of a sample can be started. After starting the rinsing procedure the data series produced during the operation can be transferred by Alpha GUARD into the connected PC and its analysis can be started. In the data series visualized by Alpha VEW-EXPERT the time range has to be marked of which the data points reflect the ^{222}Rn activity concentration resulting from the finished degassing process in the gas phase of the measurement setup. For these data points the arithmetic mean has to be calculated (AquaKIT 1999).

2.2.2 Gamma Spectroscopy

Radioactive analysis in environmental samples often encounters with difficulty in measuring low levels of radioactivity. However gamma spectrometry is a useful tool in the analysis of natural radionuclides at environmental concentrations. It is a relative method of analysis and has the advantage of being simple and essentially nondestructive. The method is based on the fact that the decay of the radioelements is accompanied by the emission of high energy gamma rays.

The applied low level background gamma ray spectrometer consists basically of 3×3 inch NaI (Tl), S-1212-I model, with a 1024 micro computer multichannel analyzer, 5510 Ortec Norland. The applied detector has a peak gamma ray efficiency of 2.3×10^{-2} at 1332 keV, energy resolution of 7.5% at 662 keV and operation bias voltage 805 V dc. The detector was housed inside a massive cylindrical lead shield with quarter 50 cm to reduce the background radiation.

The detector is connected to preamplifier, main amplifier, analogue to digital converter and multichannel analyzer as shown in the block diagram in figure 2. 14. The preamplifier integrates the current resulting from the photomultiplier tube produced by the absorption of gamma ray photons, and produces in turn an output voltage pulses with height proportional to the energy of the incident photon. Since the typical output voltage range from zero to around tenths of a volt, therefore, the pulses must be amplified in

order for them to fall within the input voltage range of the analog to digital converter ADC by connecting the detector to the external amplifier. The main amplifier should be adjusted to a known calibration source (so that the energy peaks are positioned in specific channels). The energy range of the data memory is known. The pulses are not counted simultaneously but are processed sequentially as the arrival at the analog to digital converter (ADC) from the main amplifier.

With the conversion gain of the ADC set to 1024, the full scale range (0-10 volts) is divided into 1024 discrete segments. Conversion gain is also referred to as resolution. The system automatically computes and displays the elapsed real time and life time, the total counts including the background, net total counts, background counts and the counting rate in each peak. The obtained data can be selectively acquired in separate memory groups ranging in size from 0-1023 channels.

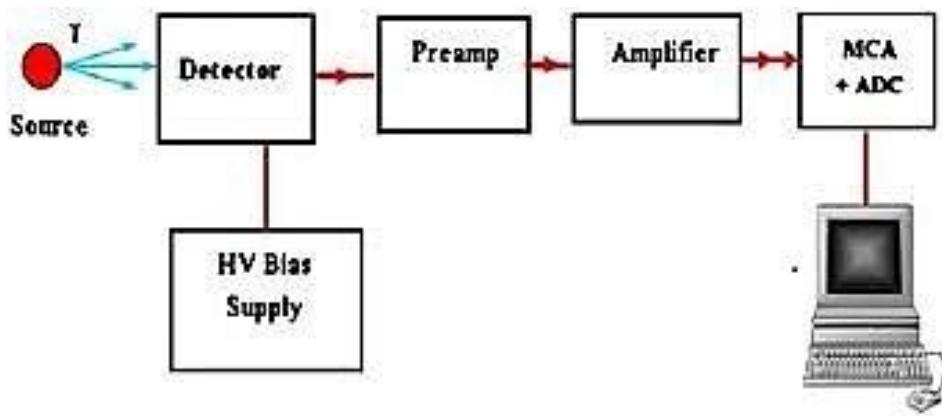


Figure 2. 14 Block diagram of a low level background gamma ray spectrometer

2.2.3 Scintillation Detectors

The major limitation of gas-filled counters, namely the low detection efficiency for X- or γ -rays, can be overcome by the use of solid or liquid detector materials, which have a much higher density than gases. Scintillation materials are frequently utilized for photon or neutron detection. In these materials a small fraction of the energy deposited by charged particles will be emitted as visible or ultraviolet light on a time scale of nanoseconds to milliseconds, whereby the intensity of the light flash is proportional to the energy deposited in the scintillators. As shown in the following figure 2. 15, a

scintillation detector consists basically of scintillators material that is optically coupled to a photomultiplier tube to convert the light photons released in the scintillators into an electrical pulse which can then be amplified and analyzed electronically.

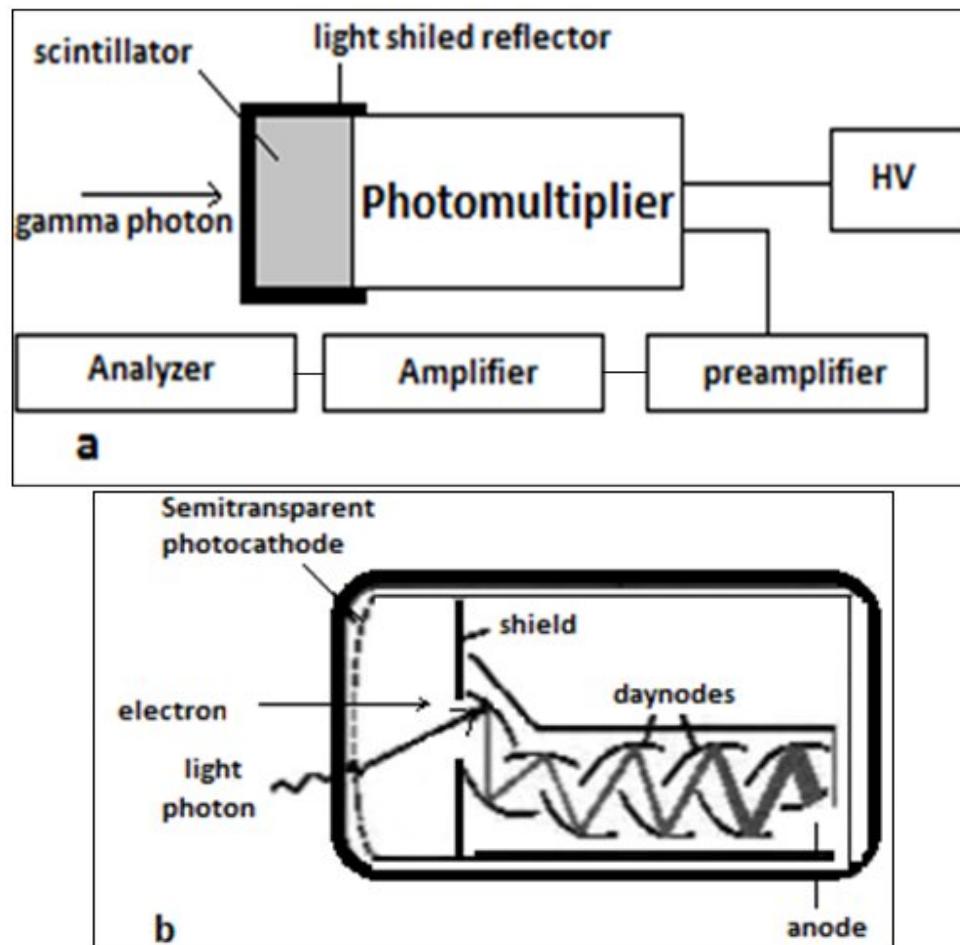


Figure 2. 15 Schematic representation of (a) a pulse-mode scintillation detector and (b) a linear focused photomultiplier tube showing the cascade effect due to amplification of electrons from the photocathode by increasing secondary emission when the electrons strike the dynodes

Scintillators fall into two major categories: inorganic and organic materials, the choice of which depends strongly on the type of measurement to be performed. Physical properties of a few representative scintillators materials are given in table 2. 3; a more comprehensive list can be found in (Knoll 2000, Leo 1994).

Table 2. 3 Physical properties of a few representative scintillators materials (Saint 2002)

Material	Type	Density (g/cm ³)	Refraction index	Light output ^a (%)	Decay Constant ^b (ns)	Wave length ^c (nm)	Main Application
Inorganic Scintillators							
NaI(Tl)	Crystal	3.67	1.85	100	250	415	γ , heavy particles
CsI (Tl)	Crystal	4.51	1.79	45	1005	550	γ , heavy particles
CsI(Na)	Crystal	4.51	1.84	85	630	420	γ , X-rays
BGO	Crystal	7.13	2.15	20	300	480	γ , X-rays
LSO	Crystal	7.40	1.82	63	40	420	γ , X-rays
Organic Scintillators							
Anthracene	Crystal	1.25	1.62	100	30	447	General purpose
Trans-stilbene	Crystal	1.16	1.63	50	4.5	410	γ , fast n
Bc 400/NE 102	Plastic	1.03	1.58	65	2.4	423	General purpose
Bc 422/NE 111	Plastic	1.03	1.58	55	1.6	370	Ultra-fast timing
Bc 501/NE 213	Liquid	0.87	1.51	78	3.2	425	Fast n with γ , discrimination
Bc 509/NE 226	Liquid	1.61	1.38	20	3.1	435	γ , insensitive to n

^a Give relative to NaI (Tl) for inorganic scintillators and relative to Anthracene for organic scintillators. The light output of Anthracene is 40-50% of NaI (Tl). ^b main component. ^c maximum emission.

Inorganic scintillators are crystals of alkali halides (such as NaI, CsI) or oxides (such as Bi₄Ge₃O₁₂, ‘BGO’) grown at high temperatures. In these materials, scintillation is a property of the electronic band structure of the crystals. When an ionizing particle enters the scintillators, it can raise electrons from the valence into the conduction band. The electrons and holes formed by this excitation process recombine and emit a photon. In the pure scintillators material, however, de-excitation is an inefficient process due to self-absorption. Therefore, small amounts of an ‘activator’ (e.g., thallium in the case of NaI) are added. These impurities create energy states within the forbidden band gap of the scintillators over which electrons can alternatively de-excite from the conduction band into the valence band. A more detailed description of the scintillation process can be found in (Knoll 2000, Tsoulfanidis 1995).

2.2.3.1 Activity Measurement

Each sample was placed in face to face geometry over the detector for 8 hours for ²²²Rn measurements, and at least 24 hours for natural radionuclide's (²²⁶Ra, ²³²Th and ⁴⁰K) measurements. Signals produced by the gamma ray detector were amplified, stored and display by multichannel analyzer as well as the energy spectra, i.e., the number of counts per unit time per energy interval.

The activity concentrations are calculated from the intensity of each line taking into account the volume of the sample, the branching ratio for the gamma decay, and the efficiency of the detector. The branching ratio is the statistical chance that a gamma ray is emitted per decaying nucleus. The efficiency of the detector represents the probability that the emitted gamma ray contributes to the line in the spectrum. Activity concentrations calculated from the intensity of several gamma rays emitted by a nucleus, are grouped together to produce a weighted average activity per nuclide. For Activity concentrations of nuclides in the same decay series, the activity concentrations are grouped in a similar way.

The ²²²Rn activity concentration of water samples is assayed by analysis of gamma peaks from ²¹⁴Bi (609 keV) and ²¹⁴Pb (295, 352 keV) (Isam 2002). The analysis of ²²⁶Ra and ²³²Th depends upon the peaks of the decay products in equilibrium with their parent nuclides. The content of ²²⁶Ra was measured using gamma-lines of 351.92 keV

(35.1%) ^{214}Pb , 609.32 keV (44.6%) ^{214}Bi , 1120 keV (15%) ^{214}Bi and 1765 keV (16%) ^{214}Bi . The activity concentration of ^{232}Th was determined using gamma energies of 238 keV (43%) ^{212}Pb and 911.16 keV (26.6%) ^{228}Ac . ^{40}K directly measured from its single peak at 1460.8 keV (10.67%) (El-Arabi 2001).

2.2.3.2 Spectrometer Adjustment

Before using the spectrometer for measurements, it's important to take into account the following considerations:

1. Energy calibration
2. Efficiency calibration
3. Background measurements

➤ Energy Calibration

Detectors measure the intensity of radiation as a function of photon energy, therefore the instrument requires to be calibrated before measurements. Calibration should be carried out for various gamma ray energies, because the indication of most instruments is energy dependent (Kiefer 1972). To calibrate the applied spectrometer for energy measurements, it is necessary to know the approximate energies of the radiation source being analyzed. Two standard point sources, one should have a relatively low energy peak and the other with a relatively high energy peak.

In the present study ^{137}Cs (662 keV) and ^{60}Co (1173 and 1332 keV) have been used, and the spectra is shown in the following figure 2. 16. Sources with widely separated energy peak will give better results than sources with narrowly separated energy peaks. The standard source was located over the detector on face-to-face geometry. After the data collection and filled on the display, the amplifier gain control is adjusted to position the higher energy peak of the two sources near the upper limit of the data display, and the data lower energy peak near the lower limit. Once the calibration peaks have been positioned, enough spectrum data from the calibration standard was collected to produce two well resolved and well defined peaks.

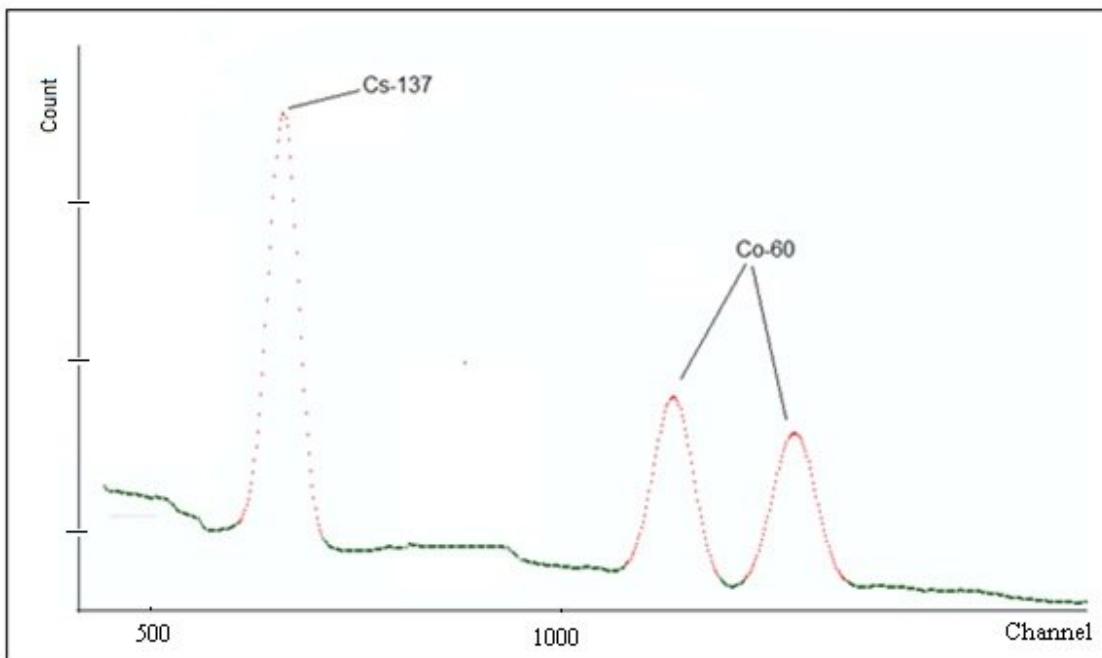


Figure 2. 16 Calibration peaks energies

➤ Efficiency Calibration

An accurate efficiency calibration of the system is necessary to quantify radionuclide's present in a sample. It is essential that this calibration be performed with great care because the accuracy of all quantitative results will depend on it. It is also essential that all system settings and adjustments be made prior to determining the efficiencies and be maintained until a new calibration is undertaken. Small changes in the settings of the system components may have slight but direct effects on counting efficiency.

Samples should be counted only in the types of container used to acquire the counting efficiencies. The density, volume and height of the sample in the container must be the same as that of the standards used for calibration. Any change of these factors will require additional calibrations to match the characteristics of the sample. In present work, it was determined the efficiency for water sample with Marinelli beaker 1.4 liter with the same geometry of the measured water samples.

➤ Preparation of Standard Water Sample Procedure

In order to make a standard water sample, first fill a standard polyethylene Marinelli beakers (1.4 liters) with distill water. Then a well-defined amount of the standard solution QCY48 (2 ml) of radionuclide's was added to water sample (Harb 2004), this standard solution was obtained from Physikalisch Technische Bundesanstalt PTB, Germany. It is mixed radionuclide gamma ray reference standard consist of a solution in 4 M HCl of the ten radionuclide's listed in the table 2. 4.

Table 2. 4 Radionuclide's used for efficiency calibration, which prepared in 4 Feb. 2010

Parent Radionuclide	Gamma ray Energy (KeV)	Gamma ray/sec./g	Uncertainty	$t_{1/2}$
Americium-241	59.54	1132	±1.5%	158047
Cadmium-109	88.03	656	±5.7%	462.6
Cobalt-57	122.1	624	±1.4%	271.4
Cerium-139	165.9	714	±1.4%	137.64
Mercury-203	279.2	2073	±1.6%	46.6
Tin-113	391.7	2191	±4.0%	115.09
Strontium-85	514	4105	±1.6%	64.84
Caesuim-137	661.6	2601	±1.6%	10958
Ytturim-88	898	6639	±1.5%	106.6
Cobalt-60	1173	3468	±1.5%	1924.9
Cobalt-60	1333	3742	±1.5%	1924.9
Ytturim-88	1836	7023	±1.4%	106.61

➤ The Efficiency Calculations

The efficiency calibration of the spectra obtained from the analysis of various background samples on detector was utilized to create distinct background files. For any calibration standard analyzed on a given detector, the corresponding background file was used to subtract contributions of background peaks from the sample peaks. The net full-energy-peak area was calculated using the efficiency calibration procedure for each background subtracted peak in the standard spectrum which corresponds to a calibrated gamma-ray emission.

The absolute detector efficiency at that energy was then calculated by dividing the net count rate in the full-energy peak by the decay corrected gamma-ray-emission rate of the standard source. After the absolute detection efficiency was determined for each calibration peak, weighted least-squares fit was made to a polynomial expression of log of efficiency vs. log of energy. Efficiency curves were constructed from these full energy peak efficiencies (Wilson 1992).

$$\varepsilon = \frac{\text{Number of pulses recorded (Experimental)}}{\text{Number of radiation quanta emitted by sources (theoretical)}} \quad \dots \text{Eq.4}$$

$$\varepsilon = \frac{N_s/t_s}{G_s \times e^{\left(-\frac{\ln 2t}{t^{1/2}} \right)}} \dots \text{Eq.5}$$

Where N_s is the Count in standard water sample, t_s is the time in a counting of standard water sample, G_s is the Counting of gamma ray of used standard solution, t is the time of decay, $t_{1/2}$ is the half-life time of radionuclide.

We used Eq. 5 for all energy of radionuclides in table 2. 4 from the measurement of calibration sources, experimental efficiencies are calculated. The experimental efficiency at energy E for a given set of measuring conditions can be computed by the formula (Negm 2009):

$$\varepsilon = A \times E^B \quad \dots \quad \text{Eq.6}$$

Where E is the energy and A, B are parameters which these parameters giving by the fitting graphs (Efficiency-Energy) of standard water samples in Marinelli beaker 1.4 liter in figure 2. 17.

From these fitting the parameters for standard water in Marinelli beaker 1.4 liter are A = 1.004 and B = -0.53, we used the Eq. 6 to determine relation between efficiency and energies table 2. 5, and then used it to determine specific activities for all radionuclides in water samples under investigation. In this work we have calibrated a NaI (Tl) detector for efficiency over the (279.2–1836.0 keV) energy range for the measurement of water samples.

The wider range in energy, the larger the number of radionuclide's whose concentration can be determined. To measure the main natural gamma ray emitters by NaI (Tl), the efficiency should be known at least from 239 keV (^{212}Pb) to 2614 keV (^{208}Tl).

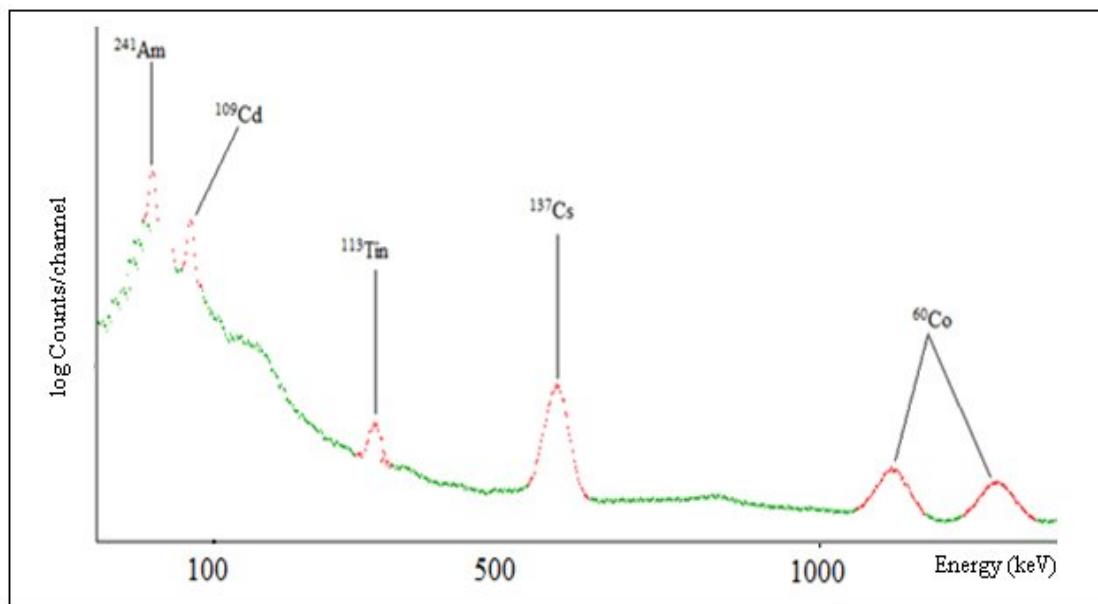


Figure 2. 17 Gamma-ray Spectrum of the standard efficiency calibration for water in marinelli beaker 1.4 liter of NaI (Tl) detector

Table 2. 5 Efficiency-Energy values for water sample in marinelli beaker 1.4 liter
for NaI (Tl) scintillation detector

Nuclides	Energy (keV)	Efficiency
²⁴¹ Am	59.54	0.027700
¹⁰⁹ Cd	88.03	0.093114
¹¹³ Tin	391.7	0.047142
¹³⁷ Cs	661.6	0.031287
⁶⁰ Co	1173	0.023403
⁶⁰ Co	1333	0.022635

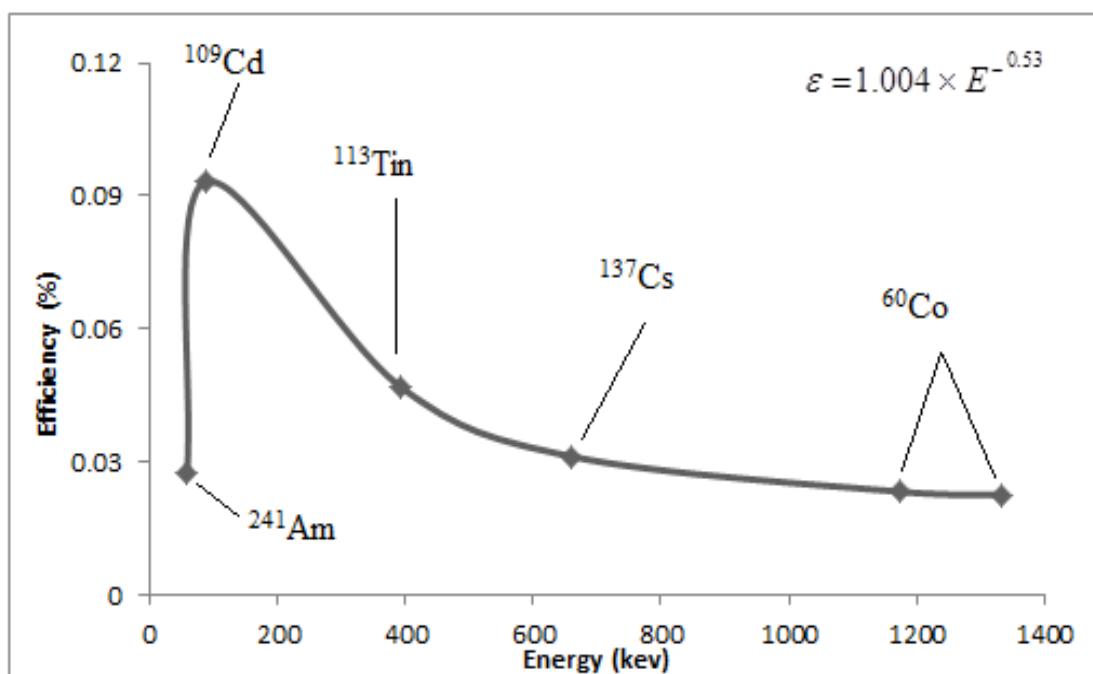


Figure 2. 18 Full energy peak efficiency as a function of gamma ray energy for a typical NaI(Tl) detector for water sample in marinelli beaker 1.4 Liter

➤ Background Measurements

The background of the system has a very significant influence on the detection limit and accuracy of the measurement of low levels of activity. The counting system must have a background as low as is attainable with a minimum of spectral lines originating from natural radionuclides which may be present in the system components and the surrounding environment, i.e. the walls, floor, etc. of the counting facility.

Background measurements should be taken as frequently as is practicable and for counting times as long as possible (in this work, the measuring time was more than 24 hours) every week in order to obtain good counting statistics.

A good practice is to record the background measurements on a control chart with statistically fixed limits. This provides a means both of checking the stability of the electronics of the system and of checking for contamination of the detector and/or shield. Should the background exceed the control limits, an immediate and thorough investigation should be made and appropriate steps taken to maintain a minimum background.

Great care should be taken to prevent any contamination of the detector, because the decontamination process is difficult, tedious, and time consuming. The detector should always be covered with a thin polyethylene film (foil) held in place over the detector by either Scotch tape or a rubber band. Radiations emitted are a beta particle with 1.314 MeV endpoint energy (89% yields), a gamma ray of 1.460 MeV energy (11%), and characteristic are X-rays following the electron capture. The high-energy gamma rays often lead to a recognizable peak in the background spectra from gamma-ray detectors, because potassium is a widespread component in concrete and other building materials. Thorium, uranium, and radium are all members of long decay chains involving daughter products that emit a mixed spectrum of alpha, beta, and gamma rays.

In the terrestrial gamma ray spectrum shown in figure 2.19, the following daughter activities can be identified: in the thorium series, ^{228}Ac , ^{224}Ra , ^{212}Pb , and ^{208}Tl ; in the uranium series, ^{226}Ra , ^{214}Pb , and ^{214}Bi . The long-lived natural activities of ^{238}U and ^{40}K are also evident.

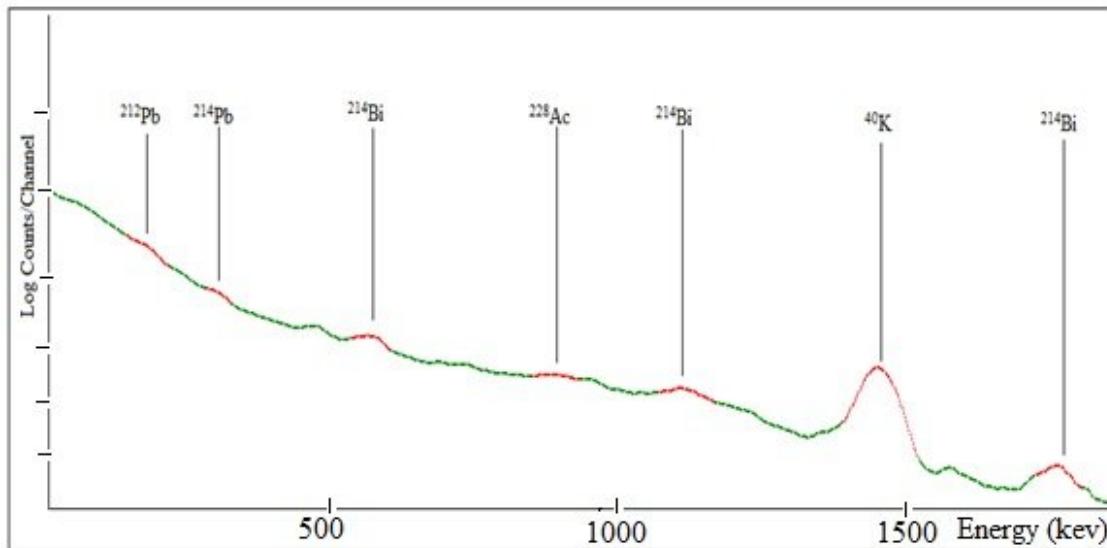


Figure 2. 19 Background spectrum

A measurable amount of background can originate with radioactivity carried by the ambient air, either in the form of trace amounts of radioactive gases or dust particles. ^{222}Rn and ^{220}Rn also present in construction materials of the laboratory. A significant component of detector background arises from the secondary radiations produced by cosmic ray interactions in the earth's atmosphere.

The primary cosmic radiation, which can be either of galactic or solar origin, is made up of charged particles and heavy ions with extremely high kinetic energies. In low-level counting experiments, it is therefore prudent to carry out a background determination near the time of the actual measurement itself. Background counts both before and after the measurement will help detect any changes in the background level (Knoll 2000).

2.2.3.3 Calculation of Activity Concentrations

Gamma ray spectrometry is a convenient method for measuring the activity of radioactive nuclei emitting gamma rays. In laboratory conditions a sample is placed close to the sensitive volume of the detector and the gamma ray spectrum is measured. In the spectrum all the photons that interact with the material within the sensitive volume of the detector are registered. Since radioactive nuclei emit a discrete spectrum of photons, peaks in the spectrum occur at these photon energies due to interactions leading to full

absorption of the photon energy within the sensitive volume. Only quantities describing the intensity of peaks in the spectra are the subject of this work.

After the measurement has been completed, the peak areas in the spectrum are calculated and corrected for counting losses. The corrected peak areas are proportional to the number of radioactive nuclei that have decayed in the sample during the time of the measurement. Neglecting the probability for coincident detection of two or more gamma rays, the factor of proportionality is given by the product of two probabilities: the probability that during the decay a gamma ray with energy E is emitted and the probability that this gamma ray is registered in the spectrum in the full-energy peak.

Following the spectrum analysis, count rates for each detected photo-peak and activity per volume unit (radiological concentration) for each of the detected nuclides are calculated. The specific activity A (Bq/l), of a nuclide and for a peak at energy E, is given by the following formula (Harb 2004):

$$A = \frac{\left[\frac{N}{T} - \frac{n}{t} \right]}{\varepsilon \times P \times M} \quad \dots \dots \dots \text{Eq.7}$$

Where A is the activity concentration Bq/l, N is the number of counts in a given peak area, T the sample counting lifetime, n is the number of counts in background peaks, t is the background counting time, P The number of gammas per disintegration of this nuclide (emission probability), M is volume in liter of the measured sample, ε is the detection efficiency at measured energy.

If there is more than one peak in the energy analysis range for a nuclide, then an attempt to average the peak activities is made by using the weighted average nuclide activity. Based on the measured gamma ray photo-peaks, emitted by specific radionuclide's in the ^{232}Th and ^{226}Ra decay series and in ^{40}K , their radiological concentrations in samples collected were determined.

Calculations relied on establishment of secular equilibrium in the samples, due to the much smaller lifetime of daughter radionuclides in the decay series of ^{232}Th and ^{226}Ra . More specifically, the ^{232}Th concentration was determined from the average Activity concentrations of ^{212}Pb , ^{208}Tl and ^{228}Ac in the samples, and that of ^{226}Ra was determined from the average activity concentrations of the ^{214}Pb and ^{214}Bi decay

products. Thus, an accurate measurement of ^{232}Th and ^{226}Ra radiological activity concentrations was made, whereas a true measurement of ^{40}K concentration was achieved.

Each tabulated value for the ^{232}Th series concentration was an average of three values obtained from the photo peaks of the ^{212}Pb (238.63 keV), ^{228}Ac (911.2 keV) and ^{208}Tl (2614 keV). The 1461 keV gamma of ^{40}K was used to determine the activity concentration of ^{40}K in different samples.

About ^{222}Rn measurements each tabulated value for the ^{222}Rn activity concentration was an average of three values obtained from the photo peaks of the ^{214}Pb (295 and 352 keV) and ^{214}Bi (609 keV) (Isam 2002).

2.2.3.4 Experimental Uncertainties

In order to comply with the standard testing laboratories are obliged to estimate the uncertainty of their measurement results (ISO 1999). The uncertainty budget used in laboratories engaged in gamma ray spectrometric measurements usually includes uncertainties from counting statistics, nuclear decay data, the counting efficiency calibration, corrections for counting losses and sample quantity. The uncertainties of the sample properties don't enter the budget explicitly but via the uncertainty of the counting efficiency calibration and uncertainty of the specific activity for radionuclides in soil samples. Namely the efficiency calibration curves are measured with calibrated samples which resemble the unknown samples as closely as possible.

It is supposed that the uncertainties of the efficiency calibration curve introduced in the process of preparation of the calibration sample resemble the uncertainties in the process of the preparation of unknown samples. If this assumption is not valid or if the efficiency calibration curves are calculated using a detector model, the uncertainties of the sample properties must explicitly enter the uncertainty budget. Frequently the samples are prepared as homogeneous cylinders by pressing or pouring the sample material into cylindrical vial which during counting is placed near the detector, coaxially along its symmetry axis. Such counting geometry can be described by the sample properties of sample radius, thickness, density and composition. It has been shown by (Korun 2001, Michel 2000), the case of interest is where the quantity Y being measured, called the

measured, is not measured directly, but is determined from N other quantities X_1, X_2, \dots, X_N through a functional relation f , often called the measurement equation:

$$Y = f(X_1, X_2, X_3, \dots, X_N) \dots \text{Eq.8}$$

Included among the quantities X_i are corrections (or correction factors), as well as quantities that take into account other sources of variability, such as different observers, instruments, samples, laboratories, and times. Thus the function f of eq. 8 should express not simply a physical law but a measurement process, and in particular, it should contain all quantities that can contribute a significant uncertainty to the measurement result. An estimate of the measured or output quantity Y , denoted by y , is obtained from eq. 5 using input estimates x_1, x_2, \dots, x_N for the values of the N input quantities X_1, X_2, \dots, X_N . Thus, the output estimate y , which is the result of the measurement, is given by

$$Y = f(x_1, x_2, x_3, \dots, x_N) \dots \text{Eq.9}$$

In general, components of uncertainty may be categorized according to the method used to evaluate them.

➤ Standard uncertainty Type A

An uncertainty component obtained by a Type A evaluation is represented by a statistically estimated standard deviation s_i , equal to the positive square root of the statistically estimated variance s_i^2 , and the associated number of degrees of freedom v_i . For such a component the standard uncertainty is $u_i = s_i$.

➤ Standard uncertainty Type B

In a similar manner, an uncertainty component obtained by a Type B evaluation is represented by a quantity u_j , which may be considered an approximation to the corresponding standard deviation; it is equal to the positive square root of u_j^2 , which may be considered an approximation to the corresponding variance and which is obtained from an assumed probability distribution based on all the available information. Since the quantity u_j^2 is treated like a variance and u_j like a standard deviation, for such a component the standard uncertainty is simply u_j .

A Type A evaluation of standard uncertainty may be based on any valid statistical method for treating data. Examples are calculating the standard deviation of the mean of a series of independent observations; using the method of least squares to fit a curve to data

in order to estimate the parameters of the curve and their standard deviations; and carrying out an analysis of variance in order to identify and quantify random effects in certain kinds of measurements.

➤ Mean and standard deviation

As an example of a Type A evaluation, consider an input quantity X_i whose value is estimated from n independent observations $X_{i,k}$ of X_i obtained under the same conditions of measurement. In this case the input estimate x_i is usually the sample mean.

$$x_i = \bar{X}_i = \frac{1}{n} \sum_{k=1}^n X_{i,k} \quad \dots \quad \text{Eq.10}$$

And the standard uncertainty $u(x_i)$ to be associated with x_i is the estimated standard deviation of the mean

$$u(x_i) = s(\bar{X}_i) \quad \dots \quad \text{Eq.11}$$

$$u(x_i) = \left(\frac{1}{n(n-1)} \sum (X_{i,k} - \bar{X}_i)^2 \right)^{1/2} \quad \dots \quad \text{Eq.12}$$

The Type B evaluation of standard uncertainty is the evaluation of the uncertainty associated with an estimate x_i of an input quantity X_i by means other than the statistical analysis of a series of observations.

The standard uncertainty $u(x_i)$ is evaluated by scientific judgment based on all available information on the possible variability of X_i . Values belonging to this category may be derived from previous measurement data; experience with or general knowledge of the behaviour and properties of relevant materials and instruments; manufacturer's specifications; data provided in calibration and other certificates; uncertainties assigned to reference data taken from handbooks. Calculation of combined standard uncertainty: if the input quantities X_i are not correlated, the combined standard uncertainties $u(y_k)$ associated with y_k are calculated by the law of uncertainty propagation as the positive square root of the combined variance $u^2(y_k)$:

$$u^2(y_k) = \sum_{i=1}^n \left(\frac{\delta G_k}{\delta x_i} \right)^2 \cdot u^2(x_i) \dots \text{Eq.13}$$

$$k = 1, \dots, n$$

If the input quantities X_i are not independent but correlated the combined standard uncertainty $u(y_k)$ has to be calculated according using covariance. If the partial derivatives are not explicitly available, they can be numerically sufficiently approximated by using the standard uncertainty $u(x_i)$ as increment of x_i :

$$\frac{\delta G_k}{\delta x_i} \approx \frac{i}{u(x_i)} \cdot \left\{ G_k(x_1, \dots, x_i + u(x_i)/2, \dots, x_n) - G_k(x_1, \dots, x_i - u(x_i)/2, \dots, x_m) \right\} \dots \text{Eq.14}$$

The standard uncertainties for specific concentration generally have to be evaluated according to the ISO Guide well in accordance with guidelines of other international bodies. In the ISO Guide, uncertainties are evaluated either by statistical methods, (type A) or by, other means, (type B), i.e., by methods of conventional statistics or Bayesian statistics. Type A uncertainties can be evaluated from repeated or counting measurements, while Type B uncertainties cannot. They are for instance uncertainties given in certificates of standard reference materials or of calibration radiation sources which are used in the evaluation of a measurement.

The evident contradiction in using different types of statistics in the definitions of the two types of uncertainties was recently overcome by the establishment of a Bayesian theory of measurement uncertainty. In this theory, uncertainties are consistently determined. They quantitatively express the actual state of incomplete knowledge of the quantities involved. The combined standard uncertainty of the measurement result y , designated by $u_c(y)$ and taken to represent the estimated standard deviation of the result, is the positive square root of the estimated variance $u_c^2(y)$ obtained from. Used here a somewhat simplified model of the evaluation in order to keep equations short: the combined standard uncertainty $u^2(\text{As})$ associated with as Eq. 7 is calculated by:

$$\begin{aligned}
u^2(A_s) &= \left(\frac{1}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot u^2(NP) + \left(\frac{NP}{t_c^2 \cdot I(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot u^2(t_c) \\
&+ \left(\frac{NP}{t_c \cdot I^2(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot u^2(I(E_\gamma)) + \left(\frac{NP}{t_c \cdot I(E_\gamma) \cdot \varepsilon^2(E_\gamma) \cdot M} \right)^2 \cdot u^2(\varepsilon(E_\gamma)) \\
&+ \left(\frac{NP}{t_c \cdot I(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M^2} \right)^2 \cdot u^2(M) \\
u^2(A_s) &= \left(\frac{NP}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot \frac{u^2(NP)}{(NP)^2} + \left(\frac{Np}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot \frac{u^2(t_c)}{t_c^2} \\
&\quad \left(\frac{NP}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot \frac{u^2(I_\gamma(E_\gamma))}{I_\gamma^2(E_\gamma)} + \left(\frac{Np}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot \frac{u^2(\varepsilon(E_\gamma))}{\varepsilon^2(E_\gamma)} \\
&+ \left(\frac{Np}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \cdot \frac{u^2(M)}{M^2} \\
u^2(A_s) &= \left(\frac{NP}{t_c \cdot I_\gamma(E_\gamma) \cdot \varepsilon(E_\gamma) \cdot M} \right)^2 \left\{ \begin{array}{l} \frac{u^2(Np)}{(Np)^2} + \frac{u^2(t_c)}{t_c^2} + \frac{u^2(I_\gamma(E_\gamma))}{I_\gamma^2(E_\gamma)} \\ + \frac{u^2(\varepsilon(E_\gamma))}{\varepsilon^2(E_\gamma)} + \frac{u^2(M)}{M^2} \end{array} \right\} \dots \text{Eq.15}
\end{aligned}$$

We can get the relative uncertainties of input value.

$$\frac{u^2(A_s)}{{A_s}^2} = \frac{u^2(Np)}{{(Np)}^2} + \frac{u^2(t_c)}{{t_c}^2} + \frac{u^2(I_\gamma(E_\gamma))}{{I_\gamma}^2(E_\gamma)} + \frac{u^2(\varepsilon(E_\gamma))}{\varepsilon^2(E_\gamma)} + \frac{u^2(M)}{{M}^2} \quad \dots \quad \text{Eq. 16}$$

Where:

$$\frac{u^2(Np)}{Np} \quad \text{From spectra evaluation}$$

$$NP = NP + N_0 - N_0 \quad \dots \quad \text{Eq.17}$$

Where the NP is net peak and N_0 is counting of background

$$u^2(NP) = u^2(NP + N_0) + u^2(N_0)$$

$$= u^2(NP) + u^2(N_0) + u^2(N_0)$$

$$= u^2(NP) + 2u^2(N_0)$$

Where $u^2(NP)$ is called variance and $u(NP)$ is the standard uncertainty

$$\frac{u(t_c)}{t_c} \prec 10^{-6} \text{ is neglected Eq.18}$$

$$\frac{u(I_\gamma(E_\gamma))}{I_\gamma(E_\gamma)} \quad \text{From table of intensity of gamma ray (Firestone 1996)}$$

$$\frac{u(\varepsilon(E_\gamma))}{\varepsilon(E_\gamma)} = 2.5\% \quad \& \quad \frac{u(M)}{M} = 1-2\% \quad (\text{González 2005}) \quad \text{Eq.19}$$

We can use Eq. 16 to get the standard uncertainties for activity of water samples.

2.2.3.5 Minimum Detectable Activity

The minimum detectable activity (MDA) is the smallest net count that can be reported with a certain degree of confidence that represents a true activity from a sample and is not a statistical variation of the background. The term MDA is not universally acceptable. In the general case, in measurements not necessarily involving radioactivity, other terms such as lowest detection limit have been used. Here, the notation and applications will be presented with the measurement of a radioactive sample in mind.

Obviously, MDA is related to low count rates. In such cases of low count rates, the person who performs the experiment faces two possible errors:

- Type 1: to state that the true activity is greater than zero when, in fact, it is zero. If this is a suspected contaminated item, the person doing the measurement will report that the item is indeed contaminated when, in fact, it is not. This error is called false positive.
- Type 2: to state that the true activity is zero when, in fact, it is not. Using the previous example, the person doing the measurement reports that the item is clean when, in fact, it is contaminated. This error is called false negative.

The outcomes of radiation measurements follow Poisson statistics, which become, essentially, Gaussian when the average is greater than about 20. For this reason, the rest of this discussion will assume that the results of individual measurements follow a normal distribution and the confidence limits set will be interpreted with that distribution in mind. Following the notation used earlier,

B = background with standard deviation σ_B

G = gross signal with standard deviation σ_G

$$n = G - B = \text{net signal with standard deviation } \sigma_n = \sqrt{\sigma_G^2 + \sigma_B^2}$$

When the net signal is zero (and has a standard deviation $\sigma_n = \sigma_0$), a critical detection limit (CDL) is defined in terms of σ_0 with the following meaning:

1. A signal lower than CDL is not worth reporting.
2. The decision that there is nothing to report has a confidence limit of $1 - \alpha$, where α is a certain fraction of the normalized Gaussian distribution (Figure 2. 20). Take as an example $\alpha = 0.05$. Then

$$\text{CDL} = k_\alpha \sigma_0 \dots \text{Eq.20}$$

With $k_\alpha = 1.645$, If $n < \text{CDL}$, one decides that the sample is not contaminated, and this decision has a 95% confidence limit.

The MDA should obviously be greater than the CDL. Keeping in mind that the possible MDA values also follow a normal distribution, a fraction β is established, meaning that a signal equal to MDA is reported as a correct/true signal with a confidence limit $1 - \beta$. The value of MDA is given by

$$\text{MDA} = \text{CDL} + k_\beta \sigma_D \dots \text{Eq. 21}$$

Where σ_D is the standard deviation of MDA (Figure 2. 20). Again, if $\beta = 0.05$, $k_\beta = 1.645$.

In most cases, in practice, $\alpha = \beta = 0.05$; then the CDL and MDA are defined with a 95% confidence limit. For radioactivity specifically, remember that:

$$\sigma^2 = \sigma_G^2 + \sigma_B^2 = (\sigma_n^2 + \sigma_B^2) + \sigma_B^2$$

And for $n = 0$, $\sigma_n = \sqrt{\text{---}} = 0$ and $\sigma = \sigma_0 = \sqrt{\sigma_n^2 + \sigma_B^2} = \sqrt{\text{---}} B$.

Then, if the 95% confidence limit is applied ($\alpha = \beta = 0.05$), CDL = 1.645 $\sigma_0 = 2.326 \sigma_B$. Values of Dl._{Th}, St. and Dl turn out to be as follow:

$$Dl_{Th} = \alpha \times \sqrt{2} \times \frac{\sigma_B}{t \times \varepsilon \times M \times R} \quad \dots \dots \dots \text{Eq.22}$$

$$St. = 2 \times Dl_{Th}.$$

$$Dl = Dl_{Th} + \beta \times \sqrt{\frac{St.}{t \times \varepsilon \times R \times M} + \frac{2\sigma_B^2}{(t \times \varepsilon \times R \times M)^2} + St.^2 \times \left(\frac{0.005}{R}\right)^2 \times (0.025)^2 \times (0.02)^2} \quad \dots \dots \dots \text{Eq.23}$$

Where Dl._{Th} is the detection limit threshold, St. is the starting value for detection limit

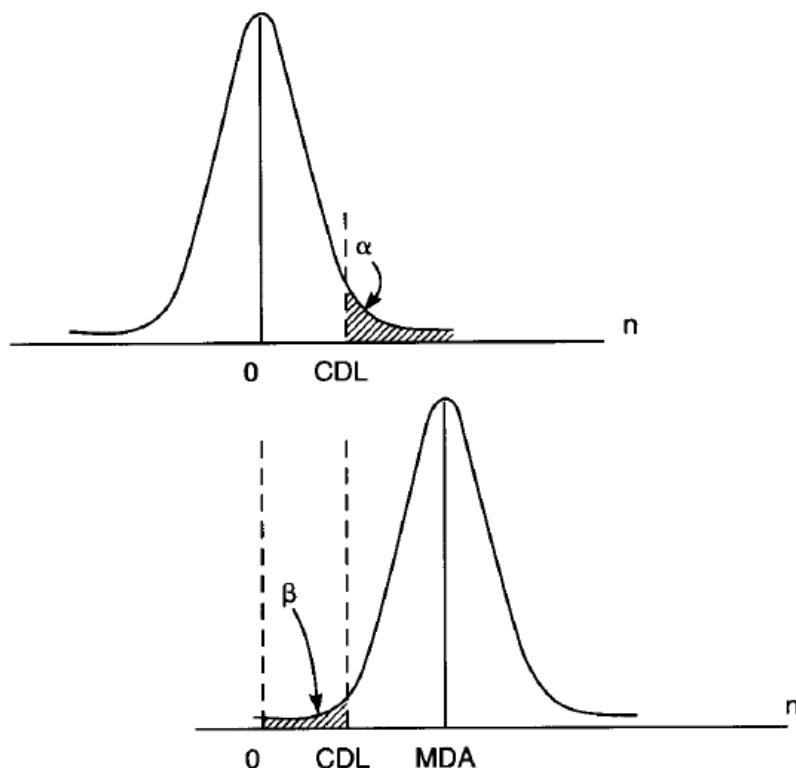


Figure 2. 20 The meaning of the critical detection limit (CDL) and minimum detectable activity (MDA) in terms of the confidence limits defined by α and β .

The values of the detection limit of the gamma-ray spectrometry system were determined from the background measurement by counting an inactive blank sample which was a 550 ml Marinelli Beaker with same geometry as the sample measurements, filled with de ionized water. The critical level, detection limit and minimum detectable activity of the gamma-ray spectrometry set-up used in the current work are reported in the following table 2. 6.

Table 2. 6 Calculated values of the lower confidence limit (LCL), upper confidence limit (UCL), detection limit (Dl) and minimum detectable activity (MDA) (Bq/l)

Energy (keV)	Radionuclide	LCL	UCL	Dl	MDA
609.3	^{214}Bi	0.3837	0.4853	0.051	0.074
1120.2	^{214}Bi	0.3561	0.6019	0.163	0.237
1764.5	^{214}Bi	0.2409	0.6040	0.274	0.399
238.6	^{212}Pb	1.0125	1.2166	0.062	0.093
911.2	^{228}Ac	0.2034	0.2695	0.031	0.035
1460.8	^{40}K	3.1107	5.0680	1.336	1.942

The final column in table 2. 6 is the minimum detectable activity (MDA) which converts the detection limit (in counts) to specific activity (Bq/l). The values from table show the minimum activity that can be detected from the blank sample. The minimum detectable activity depends on the gamma-ray energies of interest and the counting efficiency of the detector at that energy. Table 2. 7 show the Calculations of LCL, UCL, and Dl.

Table 2. 7 Calculation of characteristics limits for ^{40}K (1460 keV) for the sample water G1 (Cristina 2000)

Characteristic Limits according to ISO 11929-7:			Model for activity per sample volume $\text{As}=(\text{Ng}-\text{N}0)/(\epsilon*\text{I}*\text{M}*\text{t})$					
Preselected parameters			Calculated parameters		kappa	1		
alpha	0.05	k_1-alpha	1.64485363	u~(0)	0.41967139	p(kappa)	0.975	
beta	0.05	k_1-beta	1.64485363	a	0.71450647	k_p	1.95996398	
1 - gamma	0.95	k_1-gamma/2	1.95996398	y/u(y)	8.19011884	q(kappa)	0.975	
guideline value	1	Bq/l		xsi	0.26848471	k_q	1.95996398	
Evaluation of the measurement and calculation of characteristic limits								
quantity		symbol	x (input)	unit	u(x) (input)	u_rel(x)	type	Cx
AERA+BCID		Ng	8210		90.6090503	0.01103643	A	0.003480444
Time of Count		t	95164.61	s	0	0		0
BCID		No	6595		81.2096053	0.01231381	A	0.003712674
Time of Count		t	89212.02	s	0	0		0
branching ratio		I	0.1		0.005	0.05	B	40.89364105
counting efficiency		epsilon	0.02195804	s**-1/Bq	0.00054895	0.025	composite	186.2354255
sample mass		M	1.37498	I	0.0274996	0.02	B	2.974126245
Results								
quantity		symbol	x (input)	unit	u(x) (input)	u_rel(x)		
Activity per unit mass		As	4.0894	Bq/l	0.49930	0.122		
best estimate		z	4.0894	Bq/l	0.49930	0.122	#REF!	
decision threshold		y*	0.6903	Bq/l	A contribution from the sample has been observed.			
detection limit		eta*	1.4290	Bq/l	The procedure is not suited for the measuring task.			
lower confidence limit		eta_l	3.1107	Bq/l				
upper confidence limit		eta_u	5.0680	Bq/l				
Measurement of the counting efficiency				Model: $\epsilon=(\text{Ne}/\text{te}-\text{No}/\text{to})/(\text{Acal}/\text{lcal})$				
noch nicht an gamma-spec angepasst								
symbol	x (input)	unit	u(x) (input)	u_rel(x)	type	Cx	u(x)*Cx	
Ne	23456		153.153518	0.0065294	A	1.6683E-06	0.00025551	
te	3600	s	0	0		0	0	
No	6595		81.2096053	0.01231381	A	6.7323E-08	5.4673E-06	
to	89212.02			0		0	0	
Acal	3700	Bq	185	0.05	B	1.0456E-05	0.00193442	
lcal	0.045		0.001	0.02222222	B	0.85974382	0.00085974	
epsilon	0.03869	s**-1/Bq	0.00213	0.05511	composite			
decision threshold		y*	0.65748268					
Starting value for detection limit			1.31496536					
detection limit		eta*	1.33656784	1st iteration				

**RESULTS
&
DISCUSSTION**

RESULTS & DISCUSSION

Measurements of natural radioactivity and radon levels in water samples from Qena governorate, Egypt, are mainly concerned with many issues:

- The first concern is to investigate the activity concentrations of ^{222}Rn in ground water and drinking water (Tap and mineral), using the ionization chamber "Alpha GUARD".
- The second concern is to determine the activity concentrations of ^{222}Rn in ground water, using gamma spectroscopy "NaI (Tl)", and make comparison between the two radon measurements techniques results.
- The third concern is to investigate the activity concentrations of natural radionuclides in the ground water samples, such as ^{40}K , as well as radionuclides from the ^{226}Ra and ^{232}Th series.
- The fourth concern is to estimate the radiation hazard health, by calculate the annual effective doses for human, by intake ^{222}Rn and the natural radionuclide's ^{226}Ra , ^{232}Th , and compare between the obtained results and the other published data.
- Finally, the obtained data makes it possible to study the correlations between the geochemical parameters such as PH, TDS, and conductivity, with the ^{222}Rn , ^{226}Ra , ^{232}Th , and ^{40}K activity concentrations in the investigated water samples.

The focus, from the radiation protection view point, is to study the activity concentrations naturally occurring radionuclides, and the extent of their exposure to population. Regarding the great benefits from the studies of natural radioactivity, and to continue the program of measuring natural radioactivity in different environmental media started in the Environmental Radioactivity Measurements Laboratory (ERML), physics department, Faculty of Science, South Valley University, Qena, Egypt since 1990 (Abbady 1995, Ahmed 1995, El-Arabi 2001, El-Arabi 2005, Mageed 2013), a survey of radon activity concentrations and the naturally occurring radionuclide's in different kinds of water samples, from different sites in Qena governorate, were conducted, and the obtained results were present in the following parts.

3.1 ^{222}Rn Activity Concentrations in Ground water Samples using Alpha GUARD

Radon originates from the radioactive decay of naturally occurring uranium, and radium deposits, these elements can be found in trace amounts in almost all soils and rocks. Being radon gas can escape from mineral surfaces, and dissolve in ground water, which can carry it away from its point of origin. We rarely find radon in significant concentrations in the surface waters, due to its rapid dispersal into the atmosphere. Smaller water system appears to be disproportionately affected by high radon (Milvy 1990, EPA 1991). Radon was first noticed in water supplies by J. J. Thomson, a pioneer in the science of radioactivity in the first decade of the 1900.

Study of environmental radioactivity revealed unusually high ground water radon concentrations in the vicinity of Raymond, Maine. In 1960, scientists began to investigate the effect of ingested and inhaled radon gas, observing the uptake of radon by digestive organs and its dispersal through the blood stream (Crawford 1990). Radon was widely recognized as a major component of our natural radiation exposure. By the late 1970, Maine had initiated a program to attempt to reduce public exposure to water borne radon, having discovered cases in which ground water concentration exceeded 1 million pCi/l (Hess 1990).

Federal action on the problem of radon in drinking water picked up in the 1980, with a nationwide program to survey drinking water supplies for radioactivity and to assess the risk to public health. Congress directed the Environmental Protection Agency (EPA 1991), to take action on radioactivity in drinking water, and in 1991 the EPA officially proposed a maximum contaminant level for radon in public drinking water of 300 pCi/l. This Level may one day become bind on public water supplies (EPA 1991).

The present investigation samples were collected from 109 ground water wells, east and west of the river Nile, within Qena governorate, Egypt. The samples sites were precisely recorded using global positioning system "GPS", as shown in figure 2. 1.

The geochemical properties of water (PH, conductivity, and total dissolved solids "TDS") were measured in the field, at the moment of sampling using portable "SensoDirect pH 200" and "Jenway Model 4520 Laboratory Conductivity/TDS Meter". The obtained results of ^{222}Rn activity concentration, coordinates, conductivity, TDS, and the well depths are presented in the following table 3. 1.

Table 3. 1 ^{222}Rn activity concentrations as well as geochemical parameters in ground water samples

Sample No.	Coordinates		Depth (m)	Conductivity (mg/l)	TDS (mg/l)	^{222}Rn (Bq/l)
	Latitude	Longitude				
Qift and Qus Area						
G1	N25.89482	E33.14201	450	969	582	3.30±0.053
G2	N25.89026	E33.14548	350	939	562	2.77±0.046
G3	N25.89325	E33.13607	480	956	574	3.83±0.083
G4	N25.88557	E33.13043	480	946	568	2.10±0.035
G5	N25.88019	E33.07744	7	3790	2270	2.18±0.050
G6	N25.88657	E33.12976	450	962	577	2.67±0.065
G7	N25.88849	E32.83353	40	285	170.6	0.04±0.025
G8	N25.84729	E32.82660	40	238	143	2.03±0.050
G9	N25.84715	E32.82684	30	317	191.3	1.18±0.029
G10	N25.82979	E32.80464	840	500	299	1.46±0.037
G11	N25.96652	E32.86623	100	1740	1041	3.71±0.084
G12	N25.96528	E32.84304	45	190.4	114.1	1.09±0.030
G13	N26.04686	E32.84185	34	418	251	3.15±0.069
G14	N26.06557	E32.84055	54	267	160.4	2.32±0.052
G15	N26.01813	E32.89098	40	1094	657	1.96±0.042
G16	N26.05649	E32.87781	75	1443	866	4.37±0.093

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G17	N26.16799	E32.75415	25	1720	1033	3.16±0.069
G18	N26.13941	E32.78475	45	885	531	1.02±0.023
G21	N26.16634	E32.80450	52	833	502	2.70±0.058
G22	N26.16399	E32.80719	57	850	510	2.50±0.054
G23	N26.16644	E32.78566	50	1243	745	4.97±0.107
G24	N26.16528	E32.75622	11	1300	783	3.02±0.065
G25	N26.14728	E32.77442	-	288	173.9	2.61±0.057
G26	N26.11864	E32.79344	20	755	455	1.52±0.034
G27	N26.10910	E32.79843	40	1000	600	1.56±0.034
G28	N26.09370	E32.80996	-	1540	930	3.25±0.070
Nakada Area						
G29	N26.12289	E32.70723	-	3300	1990	5.27±0.113
G30	N26.11743	E32.72631	12.5	541	325	1.94±0.043
G31	N26.11740	E32.72662	14.5	832	501	0.65±0.015
G32	N26.11659	E32.72829	12	425	255	2.66±0.057
G33	N26.02278	E32.74951	8	1055	645	0.68±0.016
G35	N25.91814	E32.70576	25	1540	925	2.35±0.052
G36	N25.91802	E32.70522	13.5	1730	1035	2.55±0.057
G37	N25.91923	E32.70407	30	2710	1627	3.25±0.071
G38	N25.93018	E32.70083	26	1645	999	6.59±0.143
G39	N25.94468	E32.71640	25	-	-	1.48±0.032
G40	N25.94542	E32.71714	12	3560	2130	1.32±0.030
G46	N26.13491	E32.68326	10	476	285	5.89±0.129
G47	N26.13502	E32.68208	-	1093	660	4.42±0.094
G58	N26.13379	E32.66696	30	1518	911	8.35±0.187
G59	N26.13360	E32.66735	35	2740	1647	7.51±0.159

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Dishna Area						
G19	N26.26677	E32.78561	-	930	558	7.22±0.155
G20	N26.25661	E32.78344	60	3470	2120	6.74±0.144
G34	N26.18366	E32.71924	-	770	460	5.29±0.114
G41	N26.18460	E32.72376	-	1280	765	0.06±0.002
G42	N26.18509	E32.71317	-	2360	1480	2.98±0.066
G43	N26.17638	E32.71298	-	1516	907	8.67±0.187
G44	N26.18247	E32.72363	-	110	65.8	2.24±0.051
G45	N26.18994	E32.73911	-	704	424	1.86±0.041
G105	N26 10.496	E32 41.766	20	1605	965	3.31±0.073
G106	N26 11.405	E32 34.325	40	758	454	3.31±0.073
G107	N26 10.972	E32 29.146	-	2770	1652	4.99±0.106
G108	N26 09.294	E32 25.814	22	2720	1630	4.10±0.090
G109	N26 09.337	E32 25.713	30	1770	1060	4.00±0.085
Nagahammady and El-Waqf Area						
G48	N26.11220	E32.58715	16	1403	838	2.79±0.059
G49	N26.11100	E32.58140	-	990	592	5.11±0.116
G50	N26.11037	E32.57325	17	944	567	3.59±0.081
G51	N26.08424	E32.50017	20	2970	1785	4.03±0.086
G52	N26.08069	E32.49827	-	3450	2080	3.36±0.073
G53	N26.07686	E32.50301	72	2200	1321	4.29±0.097
G54	N26.07661	E32.50501	29	2700	1621	7.57±0.169
G55	N26.07499	E32.50992	28	1439	860	3.63±0.078
G56	N26.08091	E32.51557	-	2220	1335	2.53±0.055
G57	N26.08750	E32.51322	85	3710	2220	2.50±0.057
G60	N26.06381	E32.50873	110	915	565	9.10±0.194

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G61	N26.05874	E32.49473	100	789	474	8.55±0.186
G62	N26.05268	E32.48327	80	1775	1065	3.00±0.066
G63	N26.08936	E32.53300	66	1056	633	2.42±0.054
G64	N26.10662	E32.59238	-	568	340	5.14±0.110
G65	N26.02805	E32.49408	96	1234	711	2.98±0.066
G66	N25.99093	E32.43481	100	1472	883	5.17±0.111
G67	N25.99089	E32.43309	100	1455	873	5.64±0.120
G68	N25.98317	E32.42750	115	1388	833	3.67±0.080
G69	N25.97070	E32.40778	80	1179	706	6.18±0.132
G70	N25.95908	E32.35483	95	3260	1959	4.52±0.102
G71	N25.95750	E32.35122	100	3420	2050	5.16±0.114
G72	N25 59.606	E32 17.821	70	834	500	2.08±0.045
G73	N25 59.253	E32 17.577	-	1981	1187	3.14±0.069
G74	N25 59.477	E32 17.492	-	919	566	6.77±0.144
G75	N25 59.348	E32 16.701	80	2340	1400	5.20±0.110
G76	N25 59.063	E32 15.986	50	1350	813	2.25±0.048
G77	N25 58.809	E32 15.660	-	1327	796	3.07±0.067
G78	N25 58.967	E32 15.791	22	1129	677	4.30±0.093
G79	N25 58.877	E32 15.207	-	2550	1527	3.46±0.074
G80	N25 58.957	E32 14.954	-	3040	1824	4.27±0.092
G81	N25 58.912	E32 14.558	-	732	439	10.07±0.219
G82	N25 58.931	E32 13.946	-	1732	1039	1.52±0.033
G83	N25 58.072	E32 13.789	30	914	549	1.59±0.035
G84	N25 58.056	E32 12.084	30	1218	732	5.31±0.116
G85	N25 58.295	E32 11.669	30	1162	697	8.69±0.194
G86	N25 58.329	E32 11.555	29	667	460	2.35±0.052

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G87	N26 00.093	E32 08.121	30	727	436	1.20±0.027
G88	N25 59.315	E32 09.737	30	1988	1193	1.81±0.039
G89	N25 59.383	E32 09.743	45	2370	1420	2.90±0.061
G90	N25 58.660	E32 11.661	60	1208	725	1.88±0.040
G91	N25 58.274	E32 11.870	60	1245	750	3.70±0.079
G92	N26 00.746	E32 06.920	60	1835	1103	2.05±0.046
G93	N26 01.167	E32 07.449	-	630	378	2.92±0.065
G94	N26 00.673	E32 07.609	-	892	535	3.93±0.088
G95	N25 59.590	E32 09.854	-	2290	1371	3.86±0.086
G96	N25 59.080	E32 10.412	40	1190	712	1.80±0.041
G97	N25 58.962	E32 10.545	35	1086	652	1.39±0.031
G98	N25 58.728	E32 11.879	35	846	509	4.97±0.110
G99	N25 58.738	E32 11.969	62	967	580	4.10±0.094
G100	N25 58.980	E32 11.937	-	1563	942	2.26±0.048
G101	N26 05.673	E32 18.395	36	700	420	1.23±0.026
G102	N26 05.844	E32 18.830	40	808	484	1.62±0.036
G103	N26 05.878	E32 18.886	-	968	281	2.19±0.047
G104	N26 05.113	E32 22.178	20	1166	699	3.36±0.074
Minimum						0.040±0.025
Maximum						10.07±0.219
Average						3.74±0.077

3.1.1 Qift and Qus Area

The obtained values of ^{222}Rn activity concentrations in these area were fluctuated between 0.040 ± 0.025 and 4.97 ± 0.107 , with an average value of 2.48 ± 0.054 Bq/l. ^{222}Rn activity concentrations for 46% of Qift and Qus area samples were fluctuated between 1.5 and 3 Bq/l, 19% of the area samples were found in concentrations less than 1.5 Bq/l, whereas 35% of the area samples were found in concentrations more than 3 Bq/l, as shown in the following figure 3. 1.

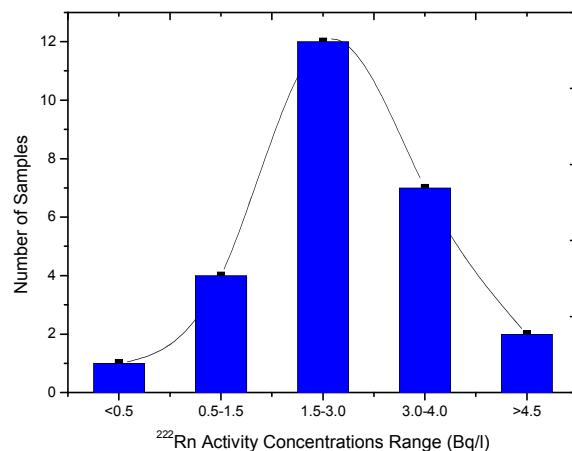


Figure 3. 1 ^{222}Rn activity concentration ranges in Qift and Qus area

3.1.2 Nakada Area

The obtained values of ^{222}Rn activity concentrations in these area were ranged between 0.65 ± 0.015 and 8.35 ± 0.187 , with an average value of 3.67 ± 0.079 Bq/l. ^{222}Rn activity concentrations for 33.3% of Nakada area samples were fluctuated between 2 and 5 Bq/l, 33.3% of area samples were found in concentrations less than 2 Bq/l, whereas 33.3% of the area samples were found in concentrations more than 5 Bq/l, as shown in the following figure 3. 2.

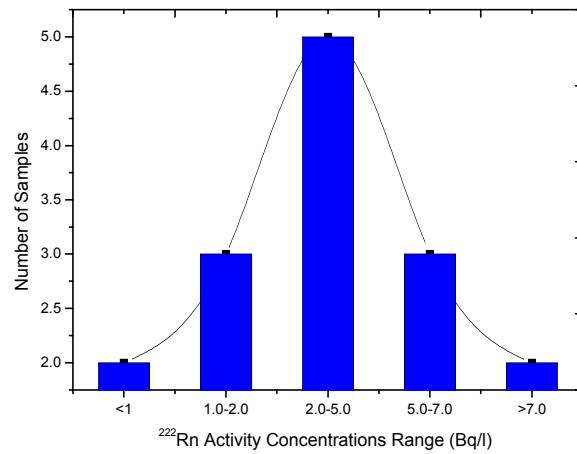


Figure 3. 2 ^{222}Rn activity concentration ranges in Nakada area

3.1.3 Dishna Area

The obtained values of ^{222}Rn activity concentrations in these area were ranged between 0.060 ± 0.002 and 8.67 ± 0.187 with an average value of 4.21 ± 0.091 Bq/l. ^{222}Rn activity concentrations for 39% of Dishna area samples were fluctuated between 3 and 5 Bq/l, 30% of the area samples were found in concentrations less than 3 Bq/l, whereas 31% of the area samples were found in concentrations more than 5 Bq/l, as shown in the following figure 3. 3.

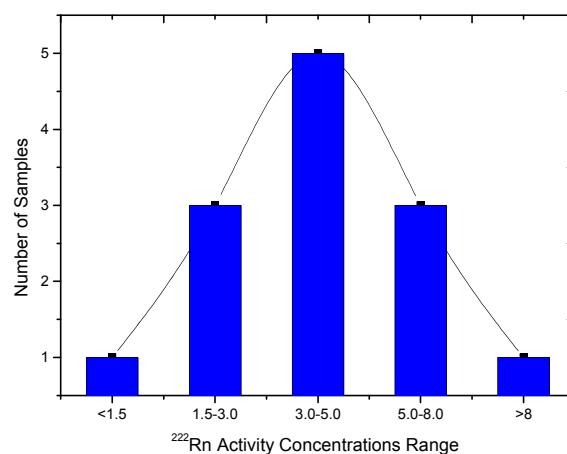


Figure 3. 3 ^{222}Rn activity concentration ranges in Dishna area

3.1.4 Nagahammady and El-Waqf Area

The obtained values of ^{222}Rn activity concentrations in these area were fluctuated between 1.20 ± 0.027 and 10.07 ± 0.219 Bq/l with an average value of 3.86 ± 0.084 Bq/l. ^{222}Rn activity concentrations for 44% of Nagahammady and El-Waqf area samples were fluctuated between 2.5 and 5 Bq/l, 30% of the area samples were found in concentrations less than 2.5 Bq/l, whereas 26% of the area samples were found in values more than 5 Bq/l, as shown in the following figure 3. 4.

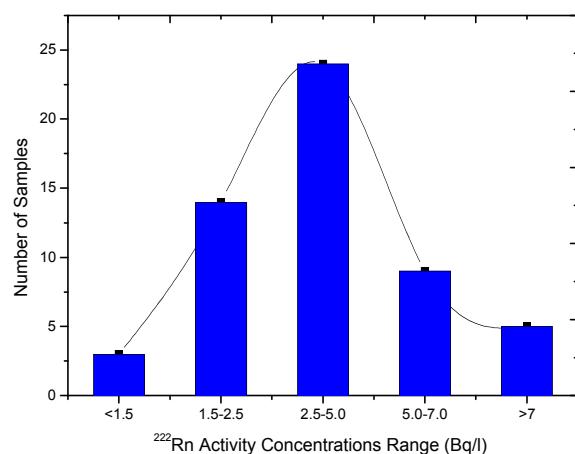


Figure 3. 4 ^{222}Rn activity concentration ranges in Nagahammady and El-Waqf area

Evidenced by measuring ^{222}Rn activity concentrations for the investigated ground water samples in the four areas under investigation, that the average values, are 2.48 ± 0.054 , 3.67 ± 0.079 , 4.21 ± 0.091 and 3.86 ± 0.08 Bq/l, in Qift and Qus, Nakada, Dishna, and Nagahammady and El-Waqf Areas, respectively, as shown in the table 3. 2, and presented in figure 3. 5.

It is noted that, the maximum average value was observed in the Dishna area, which is due to that, this area is characterized by shortness of the area enclosed between mountainous areas and the river Nile, this mountainous region is characterized as close to Wadi Qena. Wadi Qena contain granite rocks, and found in a higher natural background than other regions in Upper Egypt, which leads to increase of activity concentrations of natural radionuclides in this area compared to the other three areas under study (Saied 1994).

Table 3. 2 The ranges and average values of ^{222}Rn activity concentrations (Bq/l) for the ground water samples under investigation in the study areas

Areas	^{222}Rn activity concentrations		
	Minimum	Maximum	Average
Qift and Qus Area	0.040±0.025	4.97±0.107	2.48±0.054
Nakada Area	0.650±0.015	8.35±0.187	3.67±0.079
Dishna Area	0.060±0.002	7.22±0.155	4.21±0.091
Nagahammady and El-Waqf Area	1.200±0.027	10.07±0.219	3.86±0.084
Total Area	0.04±0.025	10.07±0.219	3.57±0.077

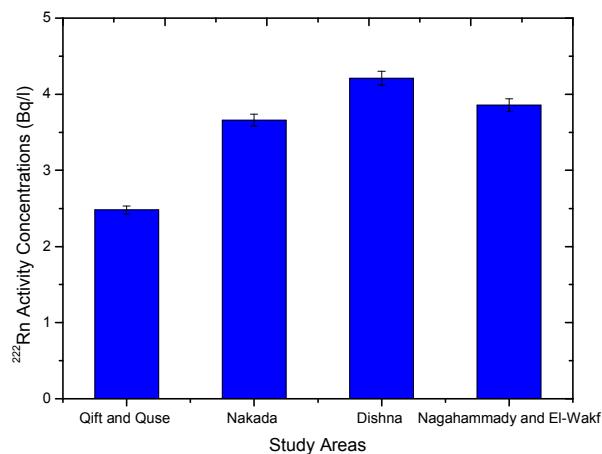


Figure 3. 5 ^{222}Rn activity concentrations for ground water samples in the study areas

3.1.5 Correlations between ^{222}Rn Activity Concentrations and the Geochemical Parameters in Ground water

3.1.5.1 TDS

TDS values were measured for ground water samples using portable Jenway Model 4520 Laboratory TDS Meter. The obtained values were fluctuated from 65.8 to 2270 mg/l. In order to study the correlation between TDS values with ^{222}Rn activity concentrations in ground water samples, it is noted that, there is no obviously correlation between them was observed, as shown in the following figure 3. 6.

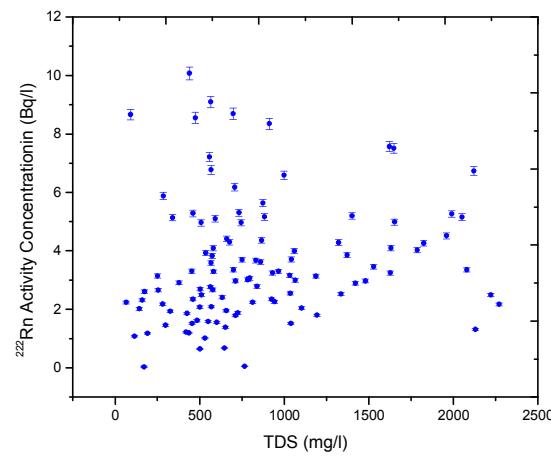


Figure 3. 6 TDS values with ^{222}Rn activity concentrationin in ground water samples

3.1.5.2 Conductivity

Conductivity values were measured for ground water samples using portable Jenway Model 4520 Laboratory TDS Meter. The obtained values were ranged between 110 and 3790 $\mu\text{s}/\text{cm}$. In order to study the correlation between conductivity values with ^{222}Rn activity concentrations in ground water samples, it is noted that there is no correlation between them was observed, as shown in the following figure 3. 7.

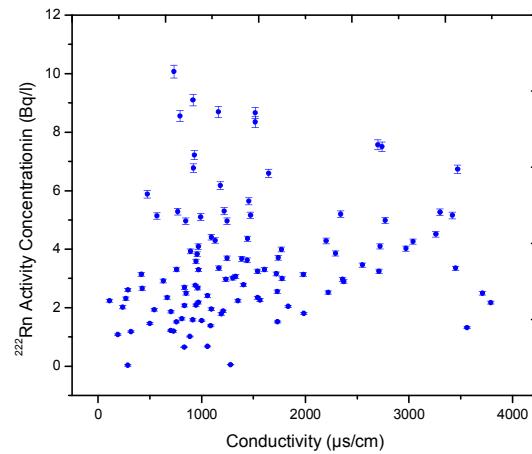


Figure 3. 7 Conductivity with ^{222}Rn activity concentration in ground water samples

3.1.5.3 PH

PH values were measured for some samples in the field at the moment of sampling, using portable Senso Direct PH 200 meter, in different sites, east and west of the River Nile, and listed with ^{222}Rn activity concentrations in table 3. 3.

In order to study the correlation between PH values and ^{222}Rn activity concentrations in the investigated samples, from figure 3. 8 it is noted that, there are a reasonable correlation between PH and ^{222}Rn activity concentrations, it decreased with increasing PH. This result can be ascribed to acid leaching and to the effect of PH on the different chemical behavior of ^{238}U and its daughters.

As PH increases, fewer minerals including U were leached from the neighboring rock or sediment. Moreover, U (VI) usually forms the UO_2^{2+} ion or its complexes which are soluble in water. When PH rises, uranium hydrolyzes and less (UO_2^{2+}) will present in the water (Khaled 2006, Lin 2003).

Table 3. 3 ^{222}Rn activity concentrations (Bq/l) with PH values in ground water samples

Sample No.	pH	^{222}Rn	Sample No.	pH	^{222}Rn
W1	6.94	3.3±0.053	W13	7.5	1.81±0.039
W2	6.96	2.77±0.046	W14	7.37	2.9±0.061
W3	6.95	3.83±0.083	W15	7.41	1.88±0.04
W4	7.25	2.18±0.05	W16	7.39	2.05±0.046
W5	7.03	2.67±0.065	W17	7.59	1.8±0.041
W6	7.22	2.03±0.05	W18	7.5	1.39±0.031
W7	7.55	1.46±0.037	W19	7.55	1.23±0.026
W8	7.57	2.32±0.052	W20	7.55	1.62±0.036
W9	7.36	1.96±0.042	W21	7.66	2.19±0.047
W10	7	3.16±0.069	W22	7.11	3.31±0.073

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W11	7.5	2.35±0.052	W23	7.2	3.41±0.078
W12	7.52	1.2±0.027	W24	7.41	1.03±0.029
W25	7.38	3.15±0.069	W32	7.25	1.84±0.039
W26	7.41	3.73±0.08	W33	7.45	1.33±0.028
W27	7.58	2.92±0.065	W34	7.5	2.81±0.06
W28	7.35	3.86±0.086	W35	6.98	6.6±0.14
W29	7.44	2.97±0.068	W36	7.34	3.51±0.075
W30	7.54	2.91±0.064	W37	7.31	4.03±0.086
W31	7.55	3.31±0.073	W38	7.48	3.72±0.079

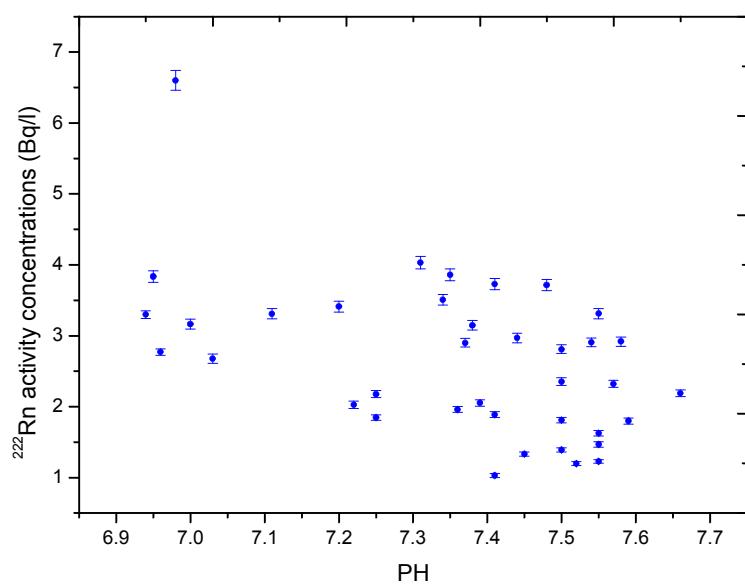


Figure 3. 8 PH values with ^{222}Rn activity concentrations in ground water samples

3.1.6 Comparison with similar studies in other countries

In order to compare between the obtained results of ^{222}Rn activity concentrations in ground water from the present work with the other published data in the other countries, table 3. 4 summarized the values of ^{222}Rn activity concentrations in some countries and those from the present wok. As can be seen from table, ^{222}Rn activity concentrations values in the present work are higher than that reported by Abbady (1995) for ground water within Qena, Egypt, Sarrou (2003) in Cyprus, and Otwoma (1998) in Kenya. Whereas the obtained values of ^{222}Rn activity concentrations are lower than that reported by Dana, (1994) in North Carolina, USA, Buchli (1989) in Switzerland, Watson (1987) in North Carolina, Field (1998) in Iowa, Galan (2004) in Spain, and by Mäkeläinen (2002) in Finland.

Table 3. 4 ^{222}Rn activity concentration in Bq/l for ground water samples in the present investigation in comparison with other countries.

Region	^{222}Rn Activity Concentrations (Bq/l)	Reference
Egypt	0.04 ± 0.025 - 10.07 ± 0.219 (3.57 ± 0.077)	Present work
North Carolina, USA	7.30	Watson 1987
North Carolina, USA	7.90	Dana 1987
Switzerland	10.4–38.3	Buchli 1989
Ghana	0.037–0.67 (0.39)	Nguelem 2013
Egypt	0.074–2.33	Abbady 1995
Iowa	0.85–87.0 (16.0)	Field 1998
Kenya	0.8–4.7	Otwoma 1998
Bangladesh	2.04–9.38 (4.46)	Alam 1999
Algeria	2.6–14	Amrani 2002

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Cyprus	0.1–5.0	Sarrou 2003
Maine (USA)	59-200 (155)	Lowry 1987
Finland	4-400 (60)	Mäkeläinen 2002
Spain	1-200 (98)	Galan 2004
Germany	1-165 (111)	Gans 1987
China	3-735 (229)	Zhuo 2001
North Carolina USA	7.30	Watson 1987
Switzerland	10.4-38.3 (3.21)	Buchli 1989
France	3-330 (296)	Saumande 1973

3.2 ^{222}Rn Activity Concentrations in Ground Water using Gamma Spectroscopy

Gamma spectroscopy technique is widely used to investigate many radionuclides in different kinds of the environmental samples. In this part from our study, ^{222}Rn activity concentrations in ground water samples were determined using a low level gamma spectrometry, based on NaI (Tl) scintillation detector. ^{222}Rn activity concentrations of samples were assayed after two hours of sampling for 8 hour counting, followed by analysis of gamma peaks from ^{214}Bi (609 keV) and ^{214}Pb (295, 352 keV) (Isam 2002), using GENEE 2000 software, for evaluating the gamma spectra.

The samples were collected from 15 ground water wells. These samples sites were chosen by random method from the whole study sites, and measured first by using Alpha GUARD. The obtaines results of ^{222}Rn activity concenterations by usning the two radon measurements techniques: ionisation chamber "Alpha GUARD" and gamma spectroscopy "NaI (Tl)", are listed in the following table 3. 5, and drown with each other in the figure 3. 9.

Table 3. 5^{222}Rn activity concentrations (Bq/l) by using the two radon measurements techniques

Sample No.	^{222}Rn using Gamma Spectroscopy	^{222}Rn using Alpha GUARD
1	3.03±0.187	3.30±0.050
2	1.99±0.100	2.10±0.030
3	2.54±0.154	2.67±0.060
4	0.48±0.024	0.04±0.030
5	1.15±0.057	1.18±0.030
6	0.92±0.046	1.09±0.030
7	2.97±0.170	3.15±0.070
8	4.13±0.252	4.37±0.090
9	0.99±0.060	1.02±0.020
10	2.68±0.133	2.70±0.060
11	3.11±0.158	3.25±0.070
12	5.20±0.317	5.27±0.110
13	2.37±0.145	2.35±0.050
14	1.90±0.097	1.86±0.040
15	0.93±0.057	1.39±0.030
Minimum	0.48±0.024	0.04±0.030
Maximum	5.20±0.317	5.27±0.110
Average	2.3±0.13	2.38±0.052

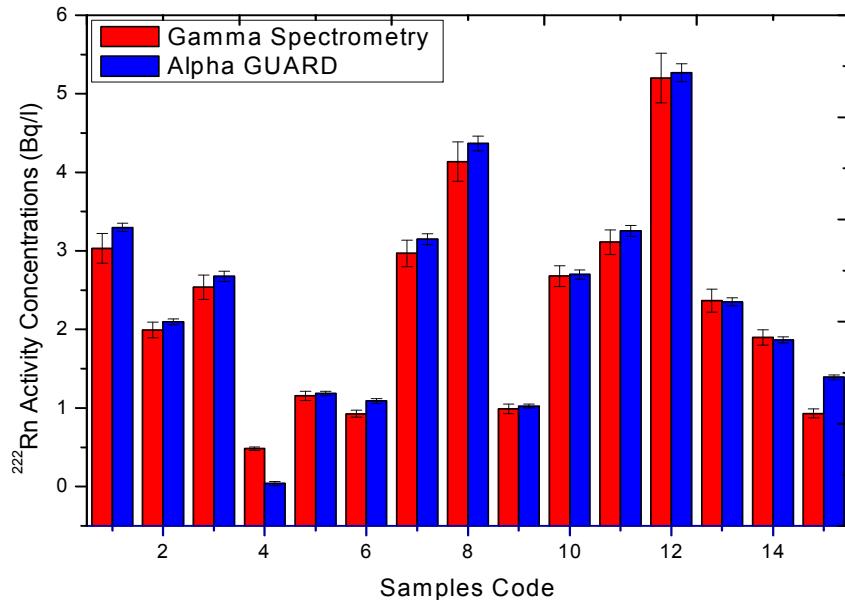


Figure 3. 9 Relation between the two radon measurements techniques

From the obtained results, It is noted that, the two radon measurements techniques results are in a good agreement. In the most investigated samples, Alpha GUARD results are slightly higher than the obtained results from gamma spectrometry; the reason may be due to that, the chance of radon escaping from samples to surrounding air in gamma spectroscopy technique is higher than Alpha GUARD technique, which is reflected on the lack of gamma spectroscopy results.

Another reason may leads to the higher results obtained from Alpha GUARD measurements than those results obtained from gamma spectrometer, ^{222}Rn concentrations in Alpha GUARD measuring technique were calculated due to directly registration of alpha particles, due to ^{222}Rn decay, but in gamma spectrometer measuring technique, ^{222}Rn concentrations were calculated due to ^{222}Rn daughters decay (^{214}Bi , ^{214}Pb), which leads to a high error rate in gamma results.

3.3 Natural Radionuclides Activity Concentrations in Ground Water

Water in the natural environment are variable in uranium content, depending mainly on factors such as contact time with U-bearing rock, U content of the contact rock, amount of evaporation and availability of complexion ions. Due to its proximity to rock and soil, ground water are somewhat enriched in respect of uranium when compared to surface waters especially in mineralized areas.

Determination of naturally occurring radionuclide's in ground water is useful as a direct input to environmental and public health studies (Isam 2002). Considering the high radio toxicity of ^{226}Ra and ^{228}Ra , their presence in water and the associated health risks require particular attention. When humans ingest radium, about 20% is absorbed into the blood stream.

Absorbed radium is initially distributed to soft tissues and bone, but its retention is mainly in growing bone (Oliveira 2001, ICRP 1993, EPA 1991). Experimental works suggested that the number of fatal cancers due to ^{222}Rn , a daughter of ^{226}Ra , ingested from drinking water may equal the fatal lung cancers due to the inhalation of indoor ^{222}Rn (Correia 1987).

Thus, high quantities of these nuclides in water necessitate the use of appropriate methods of elimination like those summarized by Sorg (Sorg 1988, 1991).

The activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K were determined over 108 sites in Qena governorate, as shown in the map figure 2. 1. The activity concentrations of radionuclides together with the values of TDS, conductivity, and well depths, are presented in the following table 3. 6.

Table 3. 6 Natural radionuclides activity concentrations (Bq/l) as well as the geochemical parameters

Sample No.	Well Depth (m)	TDS (mg/l)	Conductivity ($\mu\text{g/l}$)	^{226}Ra	^{232}Th	^{40}K
Qift and Qus Area						
G1	450	582	969	0.443±0.022	0.451±0.027	4.09±0.352
G2	350	562	939	0.349±0.017	0.284±0.017	4.19±0.360
G3	480	574	956	0.393±0.02	0.325±0.020	4.72±0.406
G4	480	568	946	0.41±0.021	0.224±0.014	4.78±0.412
G5	7	2270	3790	0.585±0.029	0.359±0.022	5.48±0.471
G6	450	577	962	0.616±0.031	0.495±0.030	5.01±0.431
G7	40	170.6	285	< MDA	0.037±0.003	5.33±0.459
G8	40	143	238	0.457±0.023	0.410±0.025	4.52±0.389
G9	30	191.3	317	0.297±0.015	0.313±0.019	4.74±0.407
G10	30-40	299	500	0.251±0.013	0.148±0.013	5.53±0.475
G11	100	1041	1740	0.478±0.024	0.375±0.032	3.18±0.273
G12	45	114.1	190.4	0.308±0.015	0.257±0.016	4.68±0.403
G13	34	251	418	0.538±0.027	0.365±0.022	4.50±0.387
G14	54	160.4	267	0.414±0.021	0.225±0.019	4.61±0.396
G15	40	657	1094	0.126±0.007	0.334±0.029	5.32±0.458
G16	75	866	1443	0.687±0.034	0.503±0.031	6.02±0.518
G17	25	1033	1720	0.579±0.029	0.442±0.027	5.06±0.435
G18	45	531	885	0.154±0.009	0.224±0.014	5.76±0.496
G21	52	502	833	0.349±0.017	0.354±0.022	5.29±0.455
G22	57	510	850	0.322±0.016	0.239±0.015	5.53±0.476
G23	50	745	1243	0.511±0.026	0.145±0.013	5.44±0.468

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G24	11	783	1300	0.606±0.030	0.601±0.037	6.19±0.533
G25	-	173.9	288	0.386±0.020	0.416±0.025	4.56±0.392
G26	20	455	755	0.209±0.010	0.206±0.013	6.39±0.550
G27	40	600	1000	0.213±0.011	0.342±0.021	4.06±0.349
G28	-	930	1540	0.523±0.026	0.499±0.030	4.41±0.379
Nakada Area						
G29	-	1990	3300	0.816±0.041	0.677±0.041	4.95±0.426
G30	12.5	325	541	0.137±0.050	0.191±0.012	6.45±0.555
G31	14.5	501	832	0.166±0.050	0.154±0.013	4.65±0.400
G32	12	255	425	0.328±0.016	0.323±0.020	5.76±0.495
G33	8	645	1055	0.126±0.007	0.251±0.015	5.10±0.439
G35	25	925	1540	0.371±0.019	0.239±0.015	5.59±0.481
G36	13.5	1035	1730	0.381±0.019	0.262±0.016	5.54±0.476
G37	30	1627	2710	0.402±0.020	0.575±0.035	4.85±0.417
G38	26	999	1645	0.747±0.038	0.663±0.057	4.31±0.371
G39	25	-	-	0.257±0.013	0.166±0.010	4.43±0.381
G40	12	2130	3560	0.215±0.011	0.128±0.009	4.19±0.360
G46	10	285	476	0.776±0.039	0.348±0.021	5.40±0.464
G47	-	660	1093	0.588±0.030	0.467±0.029	5.83±0.502
G58	30	911	1518	1.353±0.082	0.817±0.070	4.22±0.363
G59	35	1647	2740	1.205±0.073	0.693±0.060	4.51±0.388
Dishna Area						
G19	-	558	930	1.219±0.074	0.712±0.043	5.15±0.443
G20	60	2120	3470	0.964±0.049	0.899±0.077	6.03±0.518
G34	-	460	770	0.732±0.036	0.577±0.035	6.75±0.581
G41	-	765	1280	0.042±0.002	0.068±0.004	5.46±0.469

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G42	-	1480	2360	0.422±0.021	0.268±0.016	5.63±0.485
G43	-	907	1516	1.540±0.094	0.757±0.065	5.46±0.470
G44	-	65.8	110	0.409±0.020	0.490±0.030	4.54±0.390
G45	-	424	704	0.219±0.011	0.117±0.008	6.46±0.556
G105	10	965	1605	0.455±0.023	0.228±0.014	4.20±0.361
G106	40	454	758	0.604±0.030	0.250±0.016	4.32±0.372
G107	-	1652	2770	0.619±0.031	0.197±0.017	4.82±0.415
G108	22	1630	2720	0.620±0.031	0.476±0.041	4.09±0.351
G109	30	1060	1770	0.507±0.025	0.423±0.026	4.46±0.384
Nagahammady and El-Waqf Area						
G48	16	838	1403	0.483±0.024	0.340±0.029	4.74±0.408
G49	-	592	990	0.801±0.049	0.657±0.040	4.36±0.375
G50	17	567	944	0.508±0.026	0.352±0.030	4.46±0.384
G52	-	2080	3450	0.353±0.019	0.521±0.032	3.50±0.301
G53	72	1321	2200	0.559±0.028	0.583±0.036	4.56±0.392
G54	29	1621	2700	1.221±0.074	0.755±0.047	4.85±0.417
G55	28	860	1439	0.573±0.028	0.352±0.030	4.65±0.400
G56	-	1335	2220	0.356±0.018	0.360±0.022	6.37±0.548
G57	85	2220	3710	0.361±0.018	0.514±0.032	4.77±0.41
G60	110	565	915	1.880±0.114	0.783±0.048	5.27±0.454
G61	100	474	789	1.409±0.086	0.627±0.041	6.49±0.558
G62	80	1065	1775	0.478±0.024	0.385±0.024	6.89±0.593
G63	66	633	1056	0.322±0.016	0.330±0.020	4.57±0.393
G64	-	340	568	0.719±0.036	0.531±0.046	4.33±0.372
G65	96	711	1234	0.482±0.024	0.218±0.019	5.73±0.493
G66	100	883	1472	0.784±0.039	0.834±0.072	4.95±0.426

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G67	100	873	1455	0.694±0.036	0.842±0.072	5.21±0.448
G68	115	833	1388	0.442±0.023	0.684±0.042	4.67±0.402
G69	80	706	1179	0.785±0.039	0.561±0.034	4.65±0.400
G70	95	1959	3260	0.601±0.030	0.505±0.043	6.07±0.522
G71	100	2050	3420	0.889±0.054	0.322±0.028	5.94±0.511
G72	70	500	834	0.416±0.021	0.240±0.015	6.31±0.543
G73	-	1187	1981	0.395±0.020	0.427±0.026	5.83±0.501
G74	-	566	919	1.062±0.065	0.747±0.064	6.10±0.524
G75	80	1400	2340	0.768±0.038	0.579±0.036	7.00±0.602
G76	50	813	1350	0.442±0.022	0.350±0.021	5.66±0.487
G77	-	796	1327	0.608±0.030	0.523±0.032	6.02±0.518
G78	22	677	1129	0.578±0.029	0.529±0.032	5.21±0.448
G79	-	1527	2550	0.484±0.024	0.524±0.032	6.17±0.531
G80	-	1824	3040	0.561±0.034	0.513±0.031	5.13±0.441
G81	-	439	732	1.930±0.117	0.725±0.044	5.14±0.442
G82	-	1039	1732	0.204±0.010	0.215±0.013	6.42±0.552
G83	30	549	914	0.179±0.009	0.246±0.015	5.44±0.468
G84	30	732	1218	0.818±0.041	0.872±0.075	5.03±0.433
G85	30	697	1162	1.246±0.076	0.605±0.052	5.68±0.489
G86	29	460	667	0.378±0.019	0.418±0.026	4.17±0.359
G87	30	436	727	0.131±0.008	0.110±0.007	4.78±0.411
G88	30	1193	1988	0.212±0.011	0.268±0.023	6.03±0.519
G89	45	1420	2370	0.325±0.020	0.143±0.009	5.23±0.450
G90	60	725	1208	0.157±0.010	0.115±0.007	4.07±0.350
G91	60	750	1245	0.422±0.021	0.312±0.019	5.16±0.444
G92	60	1103	1835	0.411±0.021	0.164±0.010	4.71±0.405

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G93	-	378	630	0.495±0.025	0.110±0.009	5.29±0.455
G94	-	535	892	0.474±0.029	0.362±0.031	5.25±0.452
G95	-	1371	2290	0.613±0.030	0.504±0.031	5.23±0.450
G96	40	712	1190	0.137±0.007	0.191±0.012	4.29±0.369
G97	35	652	1086	0.123±0.007	0.109±0.007	4.39±0.378
G98	35	509	846	0.586±0.029	0.298±0.026	4.24±0.365
G99	62	580	967	0.497±0.025	0.170±0.010	4.13±0.355
G100	-	942	1563	0.277±0.014	0.118±0.007	5.42±0.466
G101	36	420	700	0.185±0.010	0.246±0.016	4.8±0.413
G102	40	484	808	0.222±0.011	0.187±0.012	4.17±0.359
G103	-	281	968	0.455±0.023	0.162±0.010	4.13±0.356
G104	20	699	1166	0.664±0.033	0.121±0.008	5.73±0.493
Minimum				0.042±0.002	0.067±0.004	3.18±0.273
Maximum				1.93±0.117	0.899±0.077	6.99±0.602
Average				0.54±0.029	0.4±0.027	5.10±0.44

3.3.1 Qift and Qus Area

The obtained values of ^{226}Ra activity concentrations in the area were fluctuated between 0.126 ± 0.007 and 0.687 ± 0.034 Bq/l with an average value of 0.41 ± 0.019 Bq/l. ^{226}Ra activity concentrations for 36% of Qift and Qus area samples were fluctuated between 0.3 and 0.45 Bq/l, 24% of the area samples were found in values less than 0.3 Bq/l, whereas 40% of the area samples were found in concentrations more than 0.45 Bq/l, as shown in the following figure 3. 10 (a).

The obtained values of ^{232}Th activity concentrations in the area were fluctuated between 0.037 ± 0.003 and 0.601 ± 0.037 , with an average value of 0.33 ± 0.021 Bq/l. ^{232}Th activity concentrations for 38.5% of the area samples were fluctuated between 0.4 and 0.5 Bq/l, 31% of the area samples were found in values less than 0.4 Bq/l, whereas 30.5% of the area samples were found in values higher than 0.5 Bq/l as shown in the following figure 3. 10 (b).

The obtained values of ^{40}K activity concentrations in the area were found in higher values, which fluctuated between 3.18 ± 0.273 and 6.39 ± 0.55 Bq/l, with an average value of 4.97 ± 0.43 Bq/l. ^{40}K activity concentrations for 54% of the area samples were fluctuated between 4.5 and 5.5 Bq/l, 23% of the area samples were found in values less than 4.5 Bq/l, whereas 22% of the area samples were found in values more than 5.5 Bq/l as shown in the following figure 3. 10 (C).

3.3.2 Nakada Area

The obtained values of ^{226}Ra activity concentrations in the area were ranged from 0.126 ± 0.007 to 1.353 ± 0.082 Bq/l, with an average value of 0.53 ± 0.034 Bq/l. ^{226}Ra activity concentrations of 33.3% for Nakada area samples were fluctuated between 0.3 and 0.7 Bq/l, 33.3% of the area samples were found in values less than 0.3 Bq/l, whereas 33.3% of the area samples were found in values more than 0.7 Bq/l as shown in the following figure 3. 11 (a).

The obtained values of ^{232}Th activity concentrations in the area were ranged from 0.128 ± 0.009 to 0.817 ± 0.07 Bq/l, with an average value of 0.39 ± 0.028 Bq/l. ^{232}Th activity concentrations for 40% of the area samples were fluctuated between 0.25 and 0.65 Bq/l, 33% of the area samples were found in values less than 0.25 Bq/l, whereas 27% of the area samples were found in values more than 0.65 Bq/l as shown in the following figure 3. 11 (b).

The obtained values of ^{40}K activity concentrations in the area were found in higher values, which fluctuated between 4.19 ± 0.36 and 6.45 ± 0.555 Bq/l with an average value of 5.1 ± 0.43 Bq/l. ^{40}K activity concentrations for 40% of the area samples were fluctuated between 4.5 and 5.5 Bq/l, 27% of the area samples were found in values less than 4.5 Bq/l, whereas 33% of the area samples were found in values more than 5.5 Bq/l as shown in the following figure 3. 11 (C).

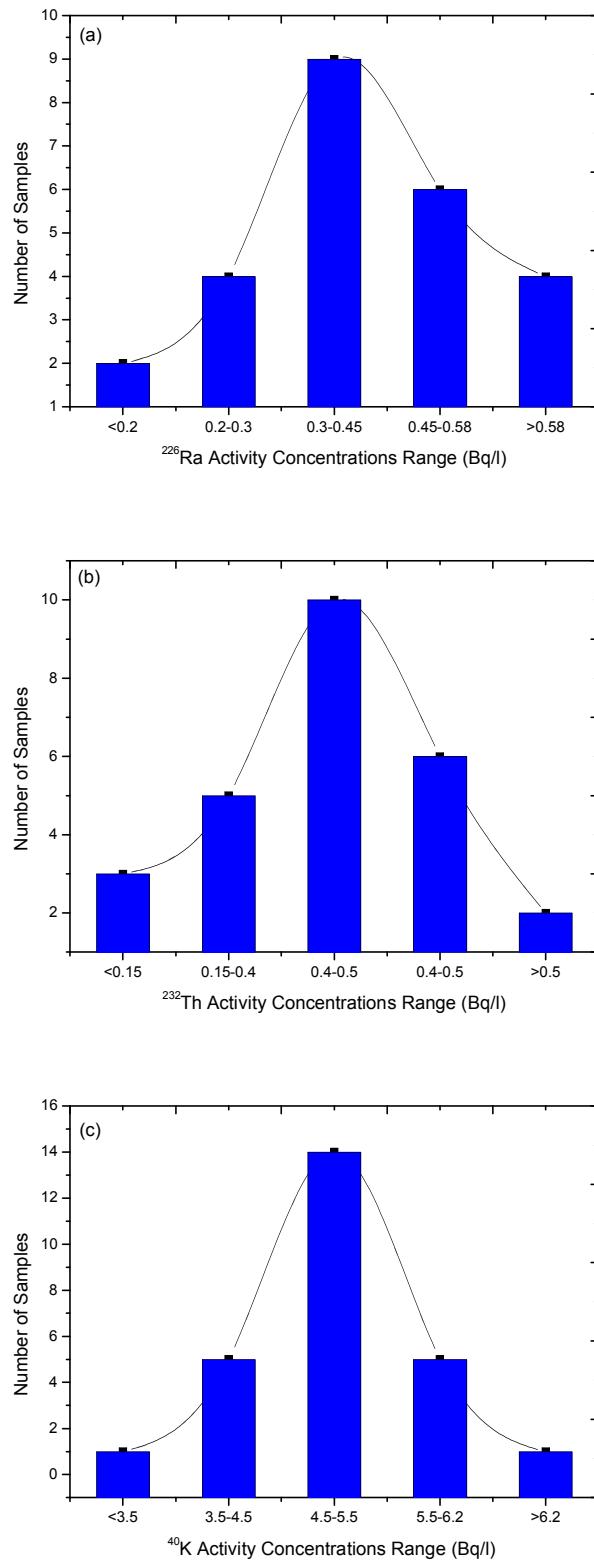


Figure 3. 10 Natural radionuclides activity concentration ranges in Qift and Qus area

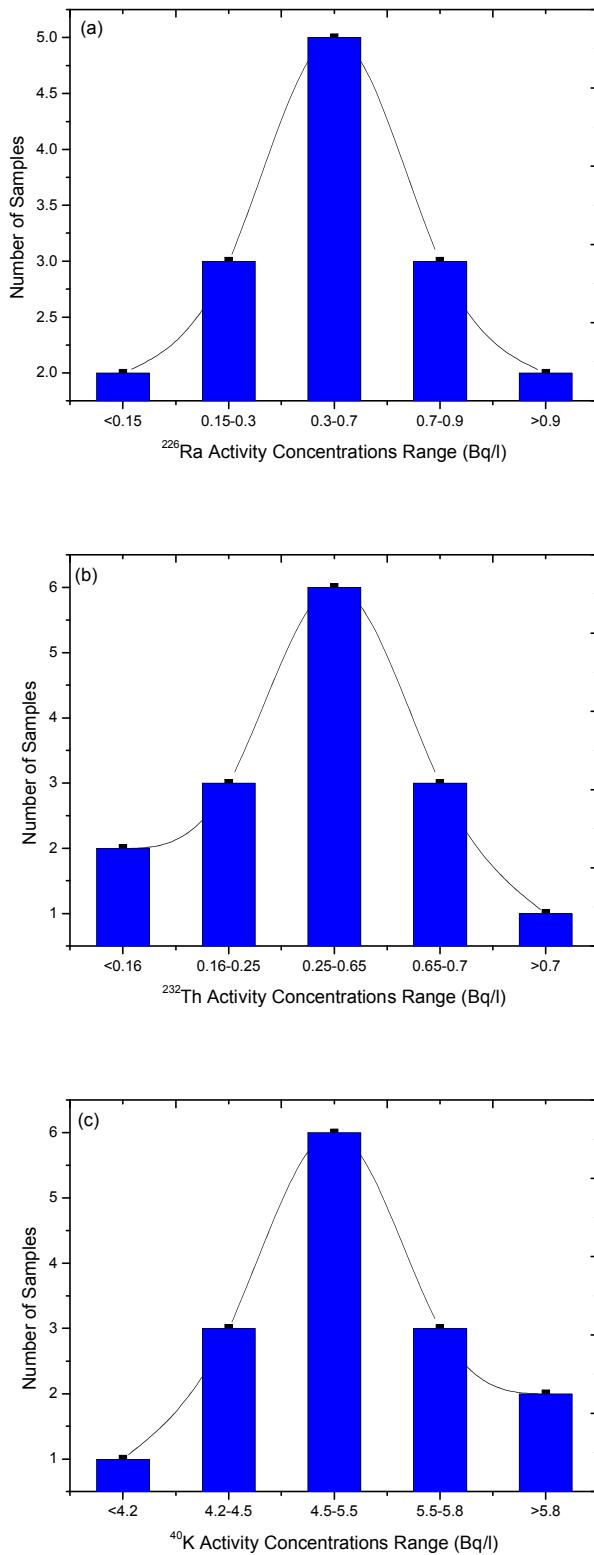


Figure 3. 11 Natural radionuclides activity concentration ranges in Nakada area

3.3.3 Dishna Area

The obtained values of ^{226}Ra concentrations in the area were fluctuated between 0.042 ± 0.002 and 1.54 ± 0.094 Bq/l, with an average value of 0.64 ± 0.034 Bq/l. ^{226}Ra activity concentrations of 46% for Dishna area samples were fluctuated between 0.44 and 0.8 Bq/l, 31% of the area samples were found in values less than 0.44 Bq/l, whereas 23% of the area samples were found in values more than 0.8 Bq/l as shown in the following figure 3. 12 (a).

The obtained values of ^{232}Th activity concentrations in the area were fluctuated between 0.068 ± 0.004 and 0.899 ± 0.077 Bq/l, with an average value of 0.42 ± 0.03 Bq/l. ^{232}Th activity concentrations of 54% of the area samples were fluctuated between 0.2 and 0.6 Bq/l, 23% of the area samples were found in values less than 0.2 Bq/l, whereas 23% of the area samples were found in values more than 0.6 Bq/l as shown in the following figure 3. 12 (b).

The obtained values of ^{40}K concentrations in the area were found in higher values, which fluctuated between 4.09 ± 0.351 and 6.75 ± 0.581 Bq/l, with an average value of 5.18 ± 0.44 Bq/l. ^{40}K activity concentrations for 46% of the area samples were fluctuated between 4.5 and 5.5 Bq/l, 23% of the area samples were found in values less than 4.5 Bq/l, whereas 31% of the area samples were found in values more than 5.5 Bq/l as shown in the following figure 3. 12 (C).

3.3.4 Nagahammady and El-Waqf Area

The obtained values of ^{226}Ra activity concentrations in the area were fluctuated between 0.123 ± 0.007 and 1.93 ± 0.117 Bq/l, with an average value of 0.58 ± 0.031 Bq/l. ^{226}Ra activity concentrations for 35% of Nagahammady and El-Waqf area samples were fluctuated between 0.4 and 0.6 Bq/l, 31% of the area samples were found in values less than 0.4 Bq/l, whereas 34% of the area samples were found in values more than 0.6 Bq/l as shown in the following figure 3. 13 (a).

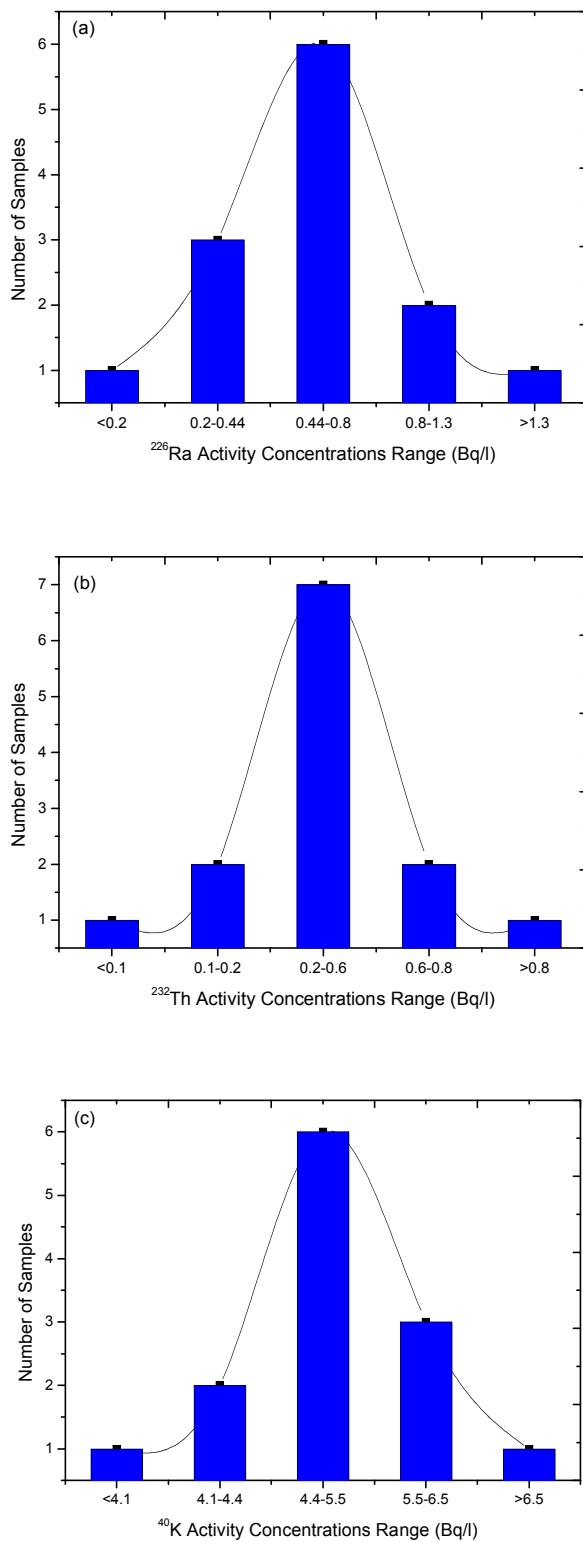


Figure 3. 12 Natural radionuclides activity concentration ranges in Dishna area

The obtained values of ^{232}Th activity concentrations in the area were fluctuated between 0.109 ± 0.007 and 0.872 ± 0.075 Bq/l, with an average value of 0.41 ± 0.028 Bq/l. ^{232}Th activity concentrations for 54% of the area samples were fluctuated between 0.22 and 0.6 Bq/l 26% of the area samples were found in values less than 0.22 Bq/l, whereas 20% of the area samples were found in values more than 0.6 Bq/l as shown in the following figure 3. 13 (b).

The obtained values of ^{40}K activity concentrations in the area were found in higher values, which fluctuated between 3.5 ± 0.301 and 7 ± 0.602 Bq/l, with an average value of 5.17 ± 0.44 Bq/l. ^{40}K activity concentrations for 46% of the area samples were fluctuated between 4.5 and 5.5 Bq/l, 22% of the area samples were found in values less than 4.5 Bq/l, whereas 32% of the area samples were found in values more than 5.5 Bq/l as shown in the following figure 3. 13 (C).

Evidenced by ^{226}Ra , ^{232}Th and ^{40}K activity concentrations measurements for ground water samples, which collected from the four areas under investigation, that the average values are (0.41 ± 0.019 , 0.33 ± 0.021 , and 4.98 ± 0.42), (0.52 ± 0.033 , 0.39 ± 0.028 , and 5.05 ± 0.43), (0.64 ± 0.034 , 0.42 ± 0.03 , and 5.18 ± 0.44) and (0.58 ± 0.031 , 0.41 ± 0.028 and $5.170.44$) Bq/l for ^{226}Ra , ^{232}Th and ^{40}K , in Qift and Qus, Nakada, Dishna, and Nagahammady and El-Waqf Areas, respectively, as shown in the following table 3. 7, and presented in figures 3. 14.

These low levels of the radionuclide's activity concentrations are due to that, the natural radioactivity of the subsoil in Qena area is generally low (Ahmed 2004). It is noted that, the maximum average values of natural radionuclides were observed in Dishna area, due to that, this area is characterized by shortness of the area enclosed between mountainous areas and the river Nile, this mountainous region is characterized as close to Wadi Qena. Wadi Qena contain granite rocks, and found in a higher natural background than other regions in Upper Egypt, which leads to increase of activity concentrations of natural radionuclides in this area compared to the other three areas under study (Sayed 1994).

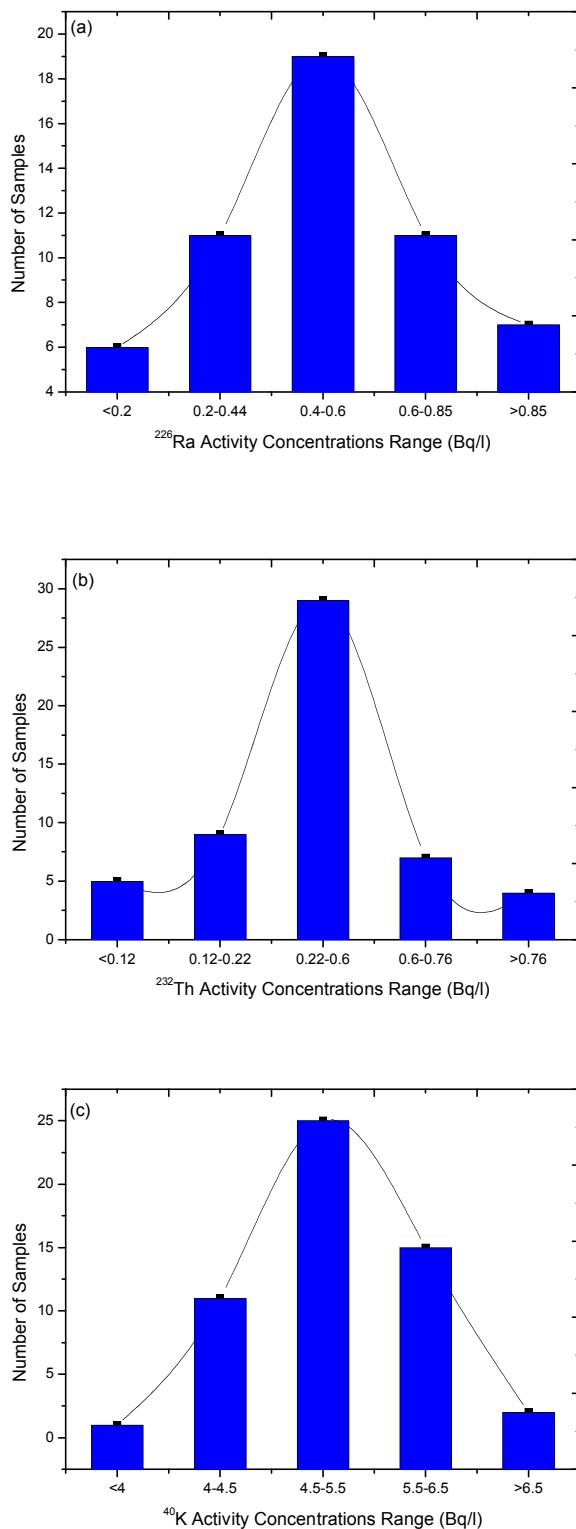


Figure 3. 13 Natural radionuclides activity concentration ranges in Nagahammady and El-Waqf area

Table 3. 7 The ranges and average values of natural radionuclides activity concentrations (Bq/l) for ground water samples

Study Areas	²²⁶ Ra			²³² Th			⁴⁰ K		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Qift and Qus	0.126±0.007	0.687±0.034	0.41±0.019	0.037±0.003	0.601±0.037	0.33±0.021	3.18±0.273	6.39±0.55	4.97±0.42
Nakada	0.126±0.007	1.205±0.073	0.53±0.033	0.128±0.009	0.817±0.07	0.4±0.028	4.19±0.360	6.45±0.555	5.1±0.43
Dishna	0.042±0.002	1.54±0.094	0.64±0.034	0.068±0.004	0.899±0.077	0.42±0.03	4.09±0.351	6.75±0.581	5.18±0.44
Nagahammady and El-Waqf	0.123±0.007	1.93±0.117	0.58±0.031	0.109±0.007	0.872±0.075	0.41±0.028	3.50±0.301	7.00±0.602	5.17±0.44
Total Area	0.042±0.002	1.93±0.117	0.54±0.029	0.067±0.004	0.899±0.077	0.4±0.027	3.18±0.273	6.99±0.602	5.10±0.44

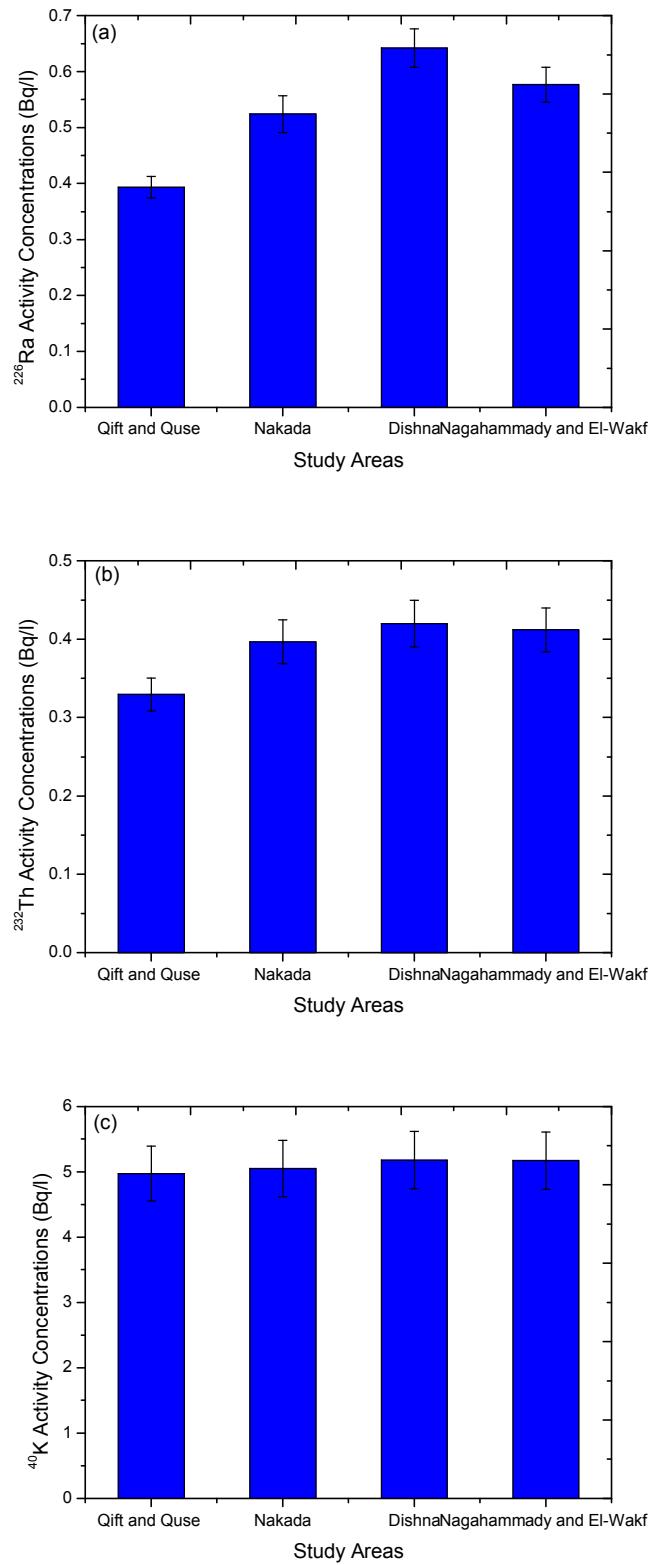


Figure 3. 14 Natural radionuclides activity concentrations in the study areas

3.3.5 Relation between ^{226}Ra and ^{222}Rn Activity Concentrations in Ground Water Samples

The natural radioactive ^{238}U series and its products distribute overall the earth's crust. The activity concentrations of these radioactive elements are transferred from the earth crust to ground water. Radon is produced naturally within the grains of the bedrock of the earth crust, which contains the ores of uranium in secular equilibrium (reached when the activity of each radioactive daughter is equal to the activity of radioactive parent). So if uranium rich in the earth crust and the neighbors' ground water, the radium concentration will be rich in the same materials, by its turn the ^{222}Rn activity concentrations will be rich.

In order to study the correlation between ^{226}Ra activity concentrations and the measured ^{222}Rn activity concentrations in ground water, the results were presented in the following table 3. 8, and plotted in the figure 3. 15. It is noted that, there are a linear correlation between ^{226}Ra and ^{222}Rn activity concentrations. The obtained linear correlations are due to the fact that, radon is produced naturally within the grains of the bedrock of the earth crust, which contains the ores of uranium in secular equilibrium.

Table 3. 8 Correlation between ^{222}Rn with ^{226}Ra activity concentrations (Bq/l) in ground water samples

Sample No.	^{222}Rn	^{226}Ra	Sample No.	^{222}Rn	^{226}Ra
G1	3.3 ± 0.053	0.443 ± 0.022	G56	2.53 ± 0.055	0.356 ± 0.018
G2	2.77 ± 0.046	0.349 ± 0.017	G57	2.50 ± 0.057	0.361 ± 0.018
G3	3.83 ± 0.083	0.393 ± 0.02	G58	8.35 ± 0.187	1.353 ± 0.082
G4	2.10 ± 0.035	0.41 ± 0.021	G59	7.51 ± 0.159	1.205 ± 0.073
G5	2.18 ± 0.050	0.585 ± 0.029	G60	9.10 ± 0.194	1.880 ± 0.114
G6	2.67 ± 0.065	0.616 ± 0.031	G61	8.55 ± 0.186	1.409 ± 0.086
G7	0.04 ± 0.025	0.03 ± 0.002	G62	3.00 ± 0.066	0.478 ± 0.024

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G8	2.03±0.050	0.457±0.023	G63	2.42±0.054	0.322±0.016
G9	1.18±0.029	0.297±0.015	G64	5.14±0.110	0.719±0.036
G10	1.46±0.037	0.251±0.013	G65	2.98±0.066	0.482±0.024
G11	3.71±0.084	0.478±0.024	G66	5.17±0.111	0.784±0.039
G12	1.09±0.030	0.308±0.015	G67	5.64±0.12	0.694±0.036
G13	3.15±0.069	0.538±0.027	G68	3.67±0.08	0.442±0.023
G14	2.32±0.052	0.414±0.021	G69	6.18±0.132	0.785±0.039
G15	1.96±0.042	0.126±0.007	G70	4.52±0.102	0.601±0.030
G16	4.37±0.093	0.687±0.034	G71	5.16±0.114	0.889±0.054
G17	3.16±0.069	0.579±0.029	G72	2.08±0.045	0.416±0.021
G18	1.02±0.023	0.154±0.009	G73	3.14±0.069	0.395±0.020
G19	7.22±0.155	1.219±0.074	G74	6.77±0.144	1.062±0.065
G20	6.74±0.144	0.964±0.049	G75	5.20±0.110	0.768±0.038
G21	2.70±0.058	0.349±0.017	G76	2.25±0.048	0.442±0.022
G22	2.50±0.054	0.322±0.016	G77	3.07±0.067	0.608±0.030
G23	4.97±0.107	0.511±0.026	G78	4.30±0.093	0.578±0.029
G24	3.02±0.065	0.606±0.03	G79	3.46±0.074	0.484±0.024
G25	2.61±0.057	0.386±0.02	G80	4.27±0.092	0.561±0.034
G26	1.52±0.034	0.209±0.01	G81	10.07±0.219	1.929±0.118
G27	1.56±0.034	0.213±0.011	G82	1.52±0.033	0.204±0.010
G28	3.25±0.07	0.523±0.026	G83	1.59±0.035	0.179±0.009
G29	5.27±0.113	0.816±0.041	G84	5.31±0.116	0.818±0.041
G30	1.94±0.043	0.137±0.05	G85	8.69±0.194	1.246±0.076
G31	0.65±0.015	0.166±0.05	G86	2.35±0.052	0.378±0.019

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G32	2.66±0.057	0.328±0.016	G87	1.20±0.027	0.131±0.008
G33	0.68±0.016	0.126±0.007	G88	1.81±0.039	0.212±0.011
G34	5.29±0.114	0.732±0.036	G89	2.90±0.061	0.325±0.020
G35	2.35±0.052	0.371±0.019	G90	1.88±0.04	0.157±0.010
G36	2.55±0.057	0.381±0.019	G91	3.70±0.079	0.422±0.021
G37	3.25±0.071	0.402±0.02	G92	2.05±0.046	0.411±0.021
G38	6.59±0.143	0.747±0.038	G93	2.92±0.065	0.495±0.025
G39	1.48±0.032	0.257±0.013	G94	3.93±0.088	0.474±0.029
G40	1.32±0.030	0.215±0.011	G95	3.86±0.086	0.613±0.030
G41	0.06±0.002	0.042±0.002	G96	1.80±0.041	0.137±0.007
G42	2.98±0.066	0.422±0.021	G97	1.39±0.031	0.123±0.007
G43	8.67±0.187	1.54±0.094	G98	4.97±0.110	0.586±0.029
G44	2.24±0.051	0.409±0.02	G99	4.10±0.094	0.497±0.025
G45	1.86±0.041	0.219±0.011	G100	2.26±0.048	0.277±0.014
G46	5.89±0.129	0.776±0.039	G101	1.23±0.026	0.185±0.010
G47	4.42±0.094	0.588±0.03	G102	1.62±0.036	0.222±0.011
G48	2.79±0.059	0.483±0.024	G103	2.19±0.047	0.455±0.023
G49	5.11±0.116	0.801±0.049	G104	3.36±0.074	0.664±0.033
G50	3.59±0.081	0.508±0.026	G105	3.31±0.073	0.455±0.023
G52	3.36±0.073	0.353±0.019	G106	3.31±0.073	0.604±0.030
G53	4.29±0.097	0.559±0.028	G107	4.99±0.106	0.619±0.031
G54	7.57±0.169	1.221±0.074	G108	4.10±0.090	0.620±0.031
G55	3.63±0.078	0.573±0.028	G109	4.00±0.085	0.507±0.025

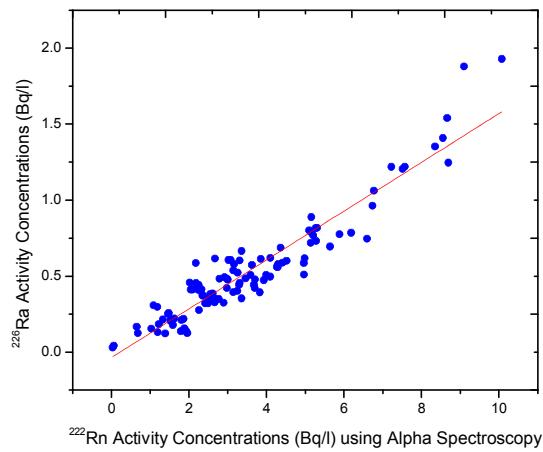


Figure 3. 15 ^{226}Ra with ^{222}Rn Activity Concentrations in Ground Water

3.3.6 Comparison with similar studies in other countries

Table 3. 9 summarized the values of ^{226}Ra , ^{232}Th and ^{40}K activity concentrations in other countries and those from the present work. As can be seen from table 3. 9, ^{226}Ra activity concentrations were found in values higher than that reported by Ahmed (2004) for ground water in Qena and Qus, Egypt, and lower than that reported by Khaled (2006) in Egypt, and by Mageed (2013) in Yemen.

Also ^{232}Th activity concentrations were found in values higher than that reported by Ahmed (2004) in Egypt, and lower than that reported by Ononugbo (2013) in Nigeria. Whereas ^{40}K activity concentrations were found in values lower than that obtained by Ononugbo (2013) in Nigeria and Khaled (2006) in Egypt.

Table 3. 9 The activity concentration in Bq/ l of water samples in the present investigation in comparison with other countries

Country	Activity concentrations (Bq/l)			Reference
	²²⁶ Ra	²³² Th	⁴⁰ K	
Egypt	0.042±0.002 - 1.93±0.117 (0.54±0.029)	0.067±0.004-0.899±0.077 (0.4±0.027)	3.18±0.273-6.99±0.602 (5.10±0.44)	Present work
Egypt	1.6-11.1	0.21-0.97	9.7-23	Khaled 2006
Yemen	2.25-3.45	0.3-1.43	26.73-43.7	Mageed 2013
Nigeria	9.22±0.82 - 16.32±0.89 (5.18±0.54)	8.46±0.61-15.18±1.72 (3.12±0.30)	44.27±2.34-67.25±3.82 (27.73±2.16)	Ononugbo 2013
Nigeria	6.03±2.10 - 14.46±5.12 (1.52±0.69)	5.54±1.76-8.43±3.01 (2.28±0.57)	100.13±26.82- 225.25±52.97 (22.05±8.09)	Ajayi 2012
Ghana	-	0.25±0.006-1.2±0.38 (0.57±0.07)	0.88±0.05-8.86±0.16 (3.67±0.211)	Nguelem 2013
Jordan	3.8-6.8	1.42-2.37	23.2-34.8	Saqan 2001
Egypt (Qena)	Mean 0.08	Mean 0.04	-	Ahmed 2004
Egypt (Safaga- Quseir)	Mean 0.1	Mean 0.05	-	

3.4 ^{222}Rn Activity Concentrations in Tap water Samples using Alpha GUARD

Measurements of ^{222}Rn activity concentrations in drinking tap water from Qena governorate, Egypt which comes from the River Nile are important, because this water is the main sources of potable water in this region, due to inadequate supply of treated water. In this part of our study ^{222}Rn activity concentrations in tap water, were measured using Alpha GUARD. The obtained results are listed in the following table 3. 10.

Table 3. 10 ^{222}Rn activity concentrations (Bq/l) in tap water samples

Measurements During the Month of February			
Sample Number	^{222}Rn	Sample Number	^{222}Rn
D1	0.050±0.0150	D21	0.047±0.0048
D2	0.047±0.0206	D22	0.035±0.0048
D3	0.062±0.014	D23	0.053±0.005
D4	0.057±0.0168	D24	0.026±0.0047
D5	0.075±0.0185	D25	0.047±0.0013
D6	0.051±0.0076	D26	0.061±0.0016
D7	0.057±0.0089	D27	0.048±0.0013
D8	0.054±0.0078	D28	0.042±0.0012
D9	0.036±0.0032	D29	0.046±0.0012
D10	0.073±0.0036	D30	0.062±0.0015
D11	0.056±0.0034	D31	0.063±0.0016
D12	0.026±0.0145	D32	0.061±0.0015
D13	0.054±0.0167	D33	0.057±0.0015
D14	0.063±0.0146	D34	0.062±0.0023

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D15	0.04 ± 0.0066	D35	0.091 ± 0.0023
D16	0.035 ± 0.0022	D36	0.061 ± 0.0018
D17	0.046 ± 0.0024	D37	0.062 ± 0.0018
D18	0.057 ± 0.0025	D38	0.08 ± 0.0019
D19	0.044 ± 0.0024	D39	0.053 ± 0.0018
D20	0.044 ± 0.0024		-
Measurements During the Month of February			
D40	0.068 ± 0.0017	D52	0.05 ± 0.0014
D41	0.065 ± 0.0029	D53	0.068 ± 0.0018
D42	0.044 ± 0.0026	D54	0.061 ± 0.0018
D43	0.064 ± 0.0029	D55	0.072 ± 0.0018
D44	0.064 ± 0.0016	D56	0.067 ± 0.0017
D45	0.068 ± 0.0017	D57	0.066 ± 0.0017
D46	0.091 ± 0.0022	D58	0.062 ± 0.0016
D47	0.073 ± 0.0018	D59	0.077 ± 0.0024
D48	0.063 ± 0.0016	D60	0.056 ± 0.0021
D49	0.038 ± 0.0011	D61	0.04 ± 0.0018
D50	0.085 ± 0.0032	D62	0.041 ± 0.0013
D51	0.049 ± 0.0013		-
Measurements during the month of April and May			
D63	0.057 ± 0.0014	D71	0.059 ± 0.0015
D64	0.046 ± 0.0012	D72	0.115 ± 0.0028

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D65	0.055 ± 0.0014	D73	0.118 ± 0.0027
D66	0.052 ± 0.0013	D74	0.062 ± 0.0016
D67	0.05 ± 0.0013	D75	0.022 ± 0.0007
D68	0.078 ± 0.0018	D76	0.043 ± 0.0011
D69	0.06 ± 0.0014	D77	0.061 ± 0.0014
D70	0.052 ± 0.0013		-

The obtained values of ^{222}Rn activity concentrations in tap water were ranged between 0.006 ± 0.00051 and 0.117 ± 0.002 Bq/l, with an average value of 0.049 ± 0.003 Bq/l. ^{222}Rn activity concentrations in 57% of samples were fluctuated between 0.045 and 0.065 Bq/l, whereas 19% of the samples were found in values less than 0.045 Bq/l, and 24% of the samples were found in values more than 0.065 Bq/l, as shown in the following figure 3. 16.

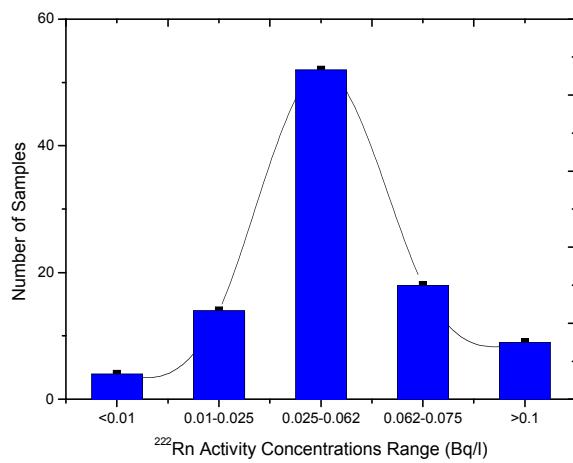


Figure 3. 16 ^{222}Rn activity concentration ranges in Qena drinking tap water

The low levels of ^{222}Rn in the obtained results are attribute to the fact that, the River Nile is considered the main source of tap water in Qena, and all tap water come from the River Nile, after passing many analyzing processes, this give a chance to escape ^{222}Rn from water, in addition, the open water contains very little dissolved radium, so we rarely find radon in significant concentrations in surface waters, due to its rapid dispersal into the atmosphere.

A set of samples have been compiled from the company drinking water and sanitation facilities at El-Himadat in the city of Qena, directly from the river Nile before entering to the chemicals treatment process inside the station, and also the same samples were collected in the same time after graduating from the treatment process. The obtained values of ^{222}Rn activity concentrations in this set of samples are shown in the following table 3. 11, and presented in figure 3. 17. It is noted that, the obtained values of ^{222}Rn activity concentrations for the samples before the chemical treatment are higher than those values obtained from the samples after the treatment process.

Table 3. 11 ^{222}Rn activity concentrations (Bq/l) in drinking tap water samples before and after the chemical treatment process

Samples before the chemical treatment process		Samples after the chemical treatment process	
Sample No.	^{222}Rn	Sample No.	^{222}Rn
DC1	0.016±0.0006	DC2	0.012±0.0006
DC3	0.022±0.0007	DC4	0.008±0.0005
DC5	0.02±0.0007	DC6	0.006±0.0005
DC7	0.018±0.0007	DC8	0.006±0.0005
DC9	0.026±0.0008	DC10	0.012±0.0006
DC11	0.02±0.0007	DC12	0.012±0.0006

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DC13	0.027±0.0008	DC14	0.011±0.0006
DC15	0.03±0.0009	DC16	0.018±0.0007
DC17	0.024±0.0008	DC18	0.013±0.0006
DC19	0.014±0.0006	DC20	0.008±0.0005
Minimum	0.014±0.0006	Minimum	0.006±0.0005
Maximum	0.03±0.0009	Maximum	0.018±0.0007
Average	0.022±0.0007	Average	0.011±0.0006

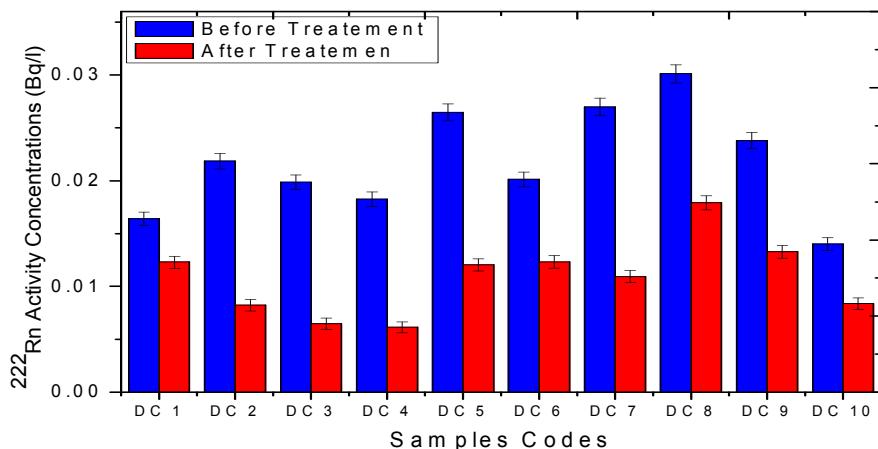


Figure 3. 17 ^{222}Rn activity concentrations (Bq/l) in drinking tap water samples before and after the chemical treatment process

3.4.1 Correlations between ^{222}Rn Activity Concentrations and the Geochemical Parameters in Tap Water

3.4.1.1 TDS

TDS values were measured for tap water samples using portable Jenway Model 4520 Laboratory TDS Meter. As shown in the following table 3. 12, the obtained values were fluctuated between 101.4 and 121.4 mg/l, with an average value of 109.74 mg/l. In order to study the correlation between TDS values with ^{222}Rn activity concentrations in tap water samples, it is noted that, there is no obviously correlation was observed, as shown in figure 3. 18.

Table 3. ^{222}Rn activity concentrations (Bq/l) with the geochemical parameters (mg/l) in Qena drinking tap water

Sample No.	^{222}Rn	TDS	Conductivity
D41	0.065±0.0029	118.8	198.1
D42	0.044±0.0026	103	172.2
D43	0.064±0.0029	101.4	169
D44	0.064±0.0016	107.4	179
D45	0.068±0.0017	110.4	186.7
D46	0.091±0.0022	108.9	181.5
D47	0.073±0.0018	112.7	187.5
D48	0.063±0.0016	111.3	185.7
D50	0.085±0.0032	121.4	202
D52	0.05±0.0014	110.2	183.7
D53	0.068±0.0018	109.1	181.9
D54	0.061±0.0018	110	183.4
D55	0.072±0.0018	109	181.6
D56	0.067±0.0017	109.2	182
D57	0.066±0.0017	108.8	181.4
D58	0.062±0.0016	109.6	182.6
D59	0.077±0.0024	115	191.6
D60	0.056±0.0021	109.5	182.5
D61	0.04±0.0018	109.5	182.5
D62	0.041±0.0013	109	187

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D63	0.057 ± 0.0014	109.1	181.9
D64	0.046 ± 0.0012	109.5	182.3
D65	0.055 ± 0.0014	111.7	185.5
D66	0.052 ± 0.0013	111.1	185.1
D67	0.05 ± 0.0013	108.4	182.2
D68	0.078 ± 0.0018	108.4	182.2
D69	0.06 ± 0.0014	110.1	183.2
D70	0.052 ± 0.0013	111	185.6
D71	0.059 ± 0.0015	108.2	180.7
D72	0.115 ± 0.0028	110.3	183.8
D73	0.118 ± 0.0027	106.3	178.1
D74	0.062 ± 0.0016	105.2	175.6
D75	0.022 ± 0.0007	111.7	185.5
D76	0.043 ± 0.0011	108.8	181.3
D77	0.061 ± 0.0014	106.9	178.1
Minimum	0.022 ± 0.0007	101.4	169
Maximum	0.118 ± 0.0027	121.4	202
Average	0.063 ± 0.001	109.74	183.32

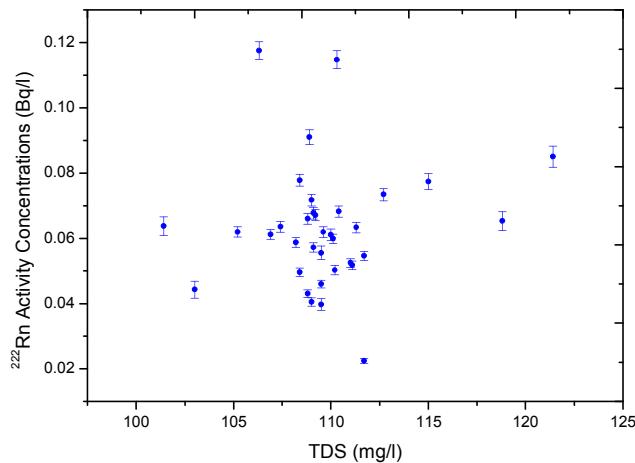


Figure 3. 18 TDS values with ^{222}Rn activity concentrations in drinking tap water samples

3.4.1.2 Conductivity

Conductivity values were measured for tap water samples using portable Jenway Model 4520 Laboratory TDS Meter. As shown in the table 3.12, the obtained values were fluctuated between 169 and 202, with an average value of 183.2 mg/l. In order to study the correlation between conductivity values with ^{222}Rn activity concentrations in tap water samples, it is noted that, there is no obviously correlation was observed, as shown in figure 3. 19.

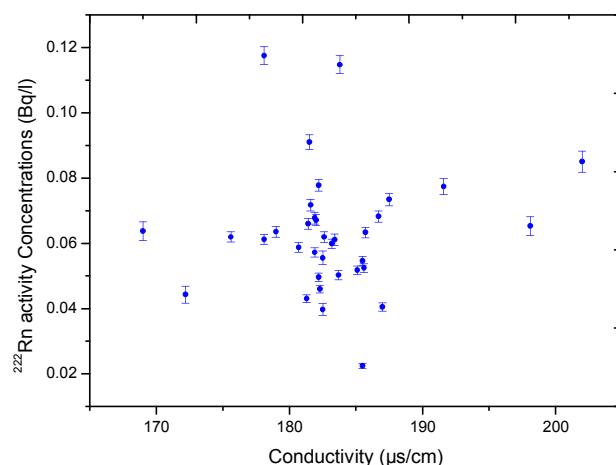


Figure 3. 19 Conductivity values with ^{222}Rn activity concentrations in drinking tap water samples

3.5 ^{222}Rn Activity Concentrations in Mineral Water using Alpha GUARD

In this part from our study ^{222}Rn activity concentrations in mineral water samples collected from Qena governorate markets were estimated. For each sample the bottle was opened, and the sample was injected to degassing vessel of the Alpha GUARD AquaKIT system by the same method of the ground water measuring.

^{222}Rn concentrations in the mineral water samples were estimated at the moment of usage, so the measurements were not corrected for delay time. The values of ^{222}Rn activity concentrations and the geochemical parameters (Calcium, Manganese, sodium, Potassium, Bicarbonate, sulfate, Chlorides, silicate and TDS) were listed in the following table 3. 13.

The values of ^{222}Rn activity concentration in the mineral water were ranged from 0.014 ± 0.003 to 0.237 ± 0.005 Bq/l, with an average value of 0.077 ± 0.0024 Bq/l. From these results, it is noted that, all mineral water results for ^{222}Rn activity concentrations are small due to that, the original sources of the measured mineral waters are ground water wells, in different places in Egypt, and this water passes many analyzing processes before using it for drinking, which give a chance for ^{222}Rn to escape from water, addition to that the half life time of ^{222}Rn is 3.82 day, so the gas will completely decay after four weeks of extracting from the well, and the calculations were performed for ^{222}Rn activity concentration at the moment of usage, without any correction for delay time.

Table 3. 13 ^{222}Rn activity concentrations (Bq/l) with the chemical parameters in mineral water (mg/l)

Sample Number	Sample Name	^{222}Rn	Ca	Mg	Na	K	HCO_3	S	Cl	Silica	TDS
M1	Baraka	0.078±0.0013	24	9.6	19	1.8	115.9	26	12	11	178
M2	Dassani	0.014±0.0037	32	8	17.5	2.2	134	13	14	10	170
M3	Aquafina	0.055±0.0053	5.2	13.2	14.5	0.8	6	65	17	2	120
M4	Shiwips	0.177±0.0070	38	19	71	4.5	205	38	86	22	402
M5	Nestleh	0.237±0.0053	16.3	6.28	16	1.4	87.8	17	88	9	132
M6	Aqua delta	0.115±0.0026	30	13.44	43	3.6	200.08	14.5	17.7	24	262
M7	Siwa	0.030±0.0010	4.8	6.36	42	16	109.8	14	29	19	200
M8	Aqua	0.017±0.0005	32	12.96	48	4.5	201.3	23	36	22	296
M9	Hayah	0.062±0.0015	5.2	8.4	37	17	95.16	14	33	19	197
M10	Aqua Paris	0.019±0.0006	-	-	-	-	-	-	-	-	-
M11	Aqua Siwa	0.020±0.0007	8	7.2	51	19	124.44	17	36	20	235
M12	Vera	0.072±0.0016	12.5	4.8	42	1.5	31.72	26	60	3	180
M13	Nahl	0.026±0.001	8	5.16	50	1.3	51.24	19	56	9	190
M14	Aman Siwa	0.160±0.002	10.4	7.2	40	17	114	16	29	20	212
Minimum		0.014±0.003	4.8	4.8	14.5	0.8	6	13	12	2	120
Maximum		0.237±0.005	38	19	71	18.5	205	65	88	24	402
Average		0.077±0.002	17.42	9.35	37.77	6.93	113.57	23.27	40	14.6	213.38

3.5.1 Comparison of results with similar in other countries

Table 3. 14 summarized the values of ^{222}Rn activity concentrations in drinking water in other countries and those from the present work. As can be seen from table, ^{222}Rn activity concentration values in drinking tap water are much higher than that reported by Karahan (2000) in Turkey. Whereas ^{222}Rn activity concentrations were found in values lower than that reported by Asaad (2008) in Iraq, Cevik (2006) in Turkey, Navjeet (2013) in India, and Otwoma (1998) in Kenya. The obtained values of ^{222}Rn activity concentration in mineral water are lower than that reported by Gans 1985 in Portugal, Tayyeb (1998) in Saudi Arabia and Ali (2013) in Iraq.

Table 3. 14 ^{222}Rn activity concentration in Bq/ l of water samples in the present investigation in comparison with other countries

Type	Countries	^{222}Rn activity concentration			References
		Minimum	Maximum	Mean	
Tap Water	Egypt	0.0061±0.0005	0.118±0.0027	0.077±0.002	Present work
	Egypt	0.07	2.33	-	Abbady 1995
	Iraq	2.01	9.61	4.693±2.213	Asaad 2008
	Turkey	5.31±0.58	18.46±1.19	10.82	Cevik 2006
	India	8.7 (pCi/L)	123.2	45.5	Navjeet 2013
	Turkey	0.019	0.041	-	Karahan 2000
	Kenya	0.8	4.7	-	Otwoma 1998
Mineral Water	Egypt	0.006±0.0005	0.118±0.0027	0.049±0.025	Present work
	Algeria	2.6	14	-	Amrani 2002
	Portugal	-	-	16.7	Gans 1985
	KSA	5.56	14.87	9.92	Tayyeb 1998
	Iraq	1.2±0.42	142±10.38	-	Ali 2013

3.6 Annual Effective Doses

Based on measured radionuclide activity concentrations in water and habitual consumption, the human health risk from irradiation due to direct ingestion can be assessed. A method to assess the annual radiological dose for a person drinking water that contains a certain level of radioactivity was applied according the equation (Alam 1999):

$$E_{\text{ff}} = K \times G \times C$$

Where E_{ff} is the annual effective dose (Sv/y), C is the radionuclide activity concentration in water (Bq/l), G is the volume of water ingested annually per liter "consumption rates", K is the effective dose equivalent conversion factor (Sv/Bq).

The annual effective doses were estimated by considering a consumption rate and the conversion factors reported by ICRP (ICRP 1996), as shown in the following table 3.15.

Table 3. 15 Consumption rates and the conversion factors (ICRP 1996)

Radionuclides	Adults	Children	Infants
^{222}Rn	1×10^{-8}	2×10^{-8}	7×10^{-8}
^{226}Ra	2.8×10^{-7}	6.2×10^{-7}	2.3×10^{-7}
^{232}Th	2.3×10^{-7}	3.5×10^{-7}	4.5×10^{-7}
Consumption Rate liter per year	500	350	150

3.6.1 Annual Effective Doses due to Ingestion of Ground water

The annual effective doses for different age groups "adults, children and infants" due to the ingestion of ground water in Qena, were calculated for some samples, used as a drinking water, considering only the ingestion from ^{222}Rn , ^{226}Ra and ^{232}Th . ^{40}K is not considered in these calculations because of the absorption of this essential element is under homeostatic control, and takes place mainly from ingested food. Thus, the contribution to dose from the ingestion of ^{40}K in water, with its relatively low dose conversion factor (5×10^{-9} Sv/Bq), will be much less than that of many other radionuclides. The obtained results were listed in the following table 3. 16.

Table 3. 16 Estimates of annual effective doses ($\mu\text{Sv}/\text{y}$) due to ingestion of natural radionuclides in Qena ground water

Sample No.	^{222}Rn			^{226}Ra			^{232}Th			Total		
	Adults	Children	Infants	Adults	Children	Infants	Adults	Children	Infants	Adults	Children	Infants
G8	10.13	14.18	21.26	64.03	99.24	65.85	47.15	50.22	27.67	121.3	163.64	114.79
G9	5.92	8.29	12.43	41.58	64.45	42.77	35.97	38.32	21.11	83.47	111.05	76.31
G10	7.32	10.25	15.38	35.18	54.52	36.18	17.05	18.16	10.01	59.55	82.94	61.57
G12	5.43	7.6	11.41	43.18	66.94	44.42	29.52	31.44	17.32	78.13	105.98	73.15
G13	15.73	22.03	33.04	75.3	116.72	77.45	41.93	44.67	24.61	132.97	183.41	135.1
G14	11.59	16.23	24.35	57.98	89.86	59.63	25.83	27.52	15.16	95.4	133.61	99.14
G25	13.06	18.29	27.43	54.03	83.75	55.57	47.89	51.01	28.11	114.98	153.05	111.12
G26	7.61	10.65	15.98	29.19	45.25	30.03	23.66	25.21	13.89	60.46	81.11	59.89
G30	9.69	13.56	20.35	19.16	29.69	19.7	21.97	23.41	12.9	50.82	66.66	52.95
G32	13.31	18.63	27.95	45.91	71.15	47.22	37.18	39.61	21.82	96.4	129.4	96.99
G34	26.44	37.01	55.52	102.49	158.85	105.41	66.38	70.71	38.96	195.3	266.57	199.89
G43	43.33	60.66	90.99	215.61	334.2	221.77	87.05	92.73	51.1	346	487.59	363.86
G44	11.22	15.7	23.55	57.28	88.79	58.92	56.32	59.99	33.06	124.82	164.48	115.53
G45	9.32	13.05	19.57	30.64	47.5	31.52	13.46	14.34	7.9	53.42	74.88	58.99

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G46	29.43	41.2	61.79	108.65	168.41	111.75	40.02	42.63	23.49	178.1	252.23	197.04
G61	42.77	59.88	89.81	197.23	305.71	202.87	72.05	76.75	42.29	312.05	442.34	334.97
G64	25.7	35.98	53.96	100.7	156.08	103.57	61.12	65.1	35.87	187.51	257.16	193.41
G81	50.37	70.52	105.77	270.1	418.66	277.82	83.38	88.81	48.94	403.85	577.99	432.53
G86	11.76	16.47	24.7	52.92	82.02	54.43	48.05	51.18	28.2	112.73	149.67	107.33
G87	5.98	8.38	12.57	18.4	28.52	18.93	12.7	13.53	7.46	37.09	50.43	38.95
G93	14.58	20.42	30.63	69.24	107.33	71.22	12.68	13.51	7.44	96.51	141.26	109.29
G101	6.13	8.58	12.87	25.85	40.07	26.59	28.32	30.17	16.62	60.31	78.82	56.09
G102	8.11	11.35	17.03	31.04	48.11	31.93	21.55	22.95	12.65	60.7	82.42	61.61
G103	10.93	15.3	22.95	63.67	98.69	65.49	18.66	19.87	10.95	93.26	133.86	99.39
G106	16.55	23.17	34.75	84.55	131.06	86.97	28.8	30.68	16.91	129.9	184.91	138.63
Minimum	5.43	7.6	11.41	18.4	28.52	18.93	12.86	13.51	7.44	37.09	50.43	38.95
Maximum	50.37	70.52	105.77	270.1	418.66	277.82	87.1	92.37	51.1	403.85	577.99	432.53
Average	16.49	23.1	34.64	75.75	117.42	77.92	39.1	41.7	22.97	131.4	182.21	135.54

The obtained values of the annual effective dose of ground water samples for adults, children and infants were ranged from 37.1 to 403.85, 50.4 to 578 and 39 to 432.53, with average values of 131.4, 182.2 and 135.5 $\mu\text{Sv}/\text{y}$, for adults, children and infants, respectively. The annual effective dose values in the investigated ground water samples, for the different age groups "Adults, children and infants", are presented in the following figure 3. 20.

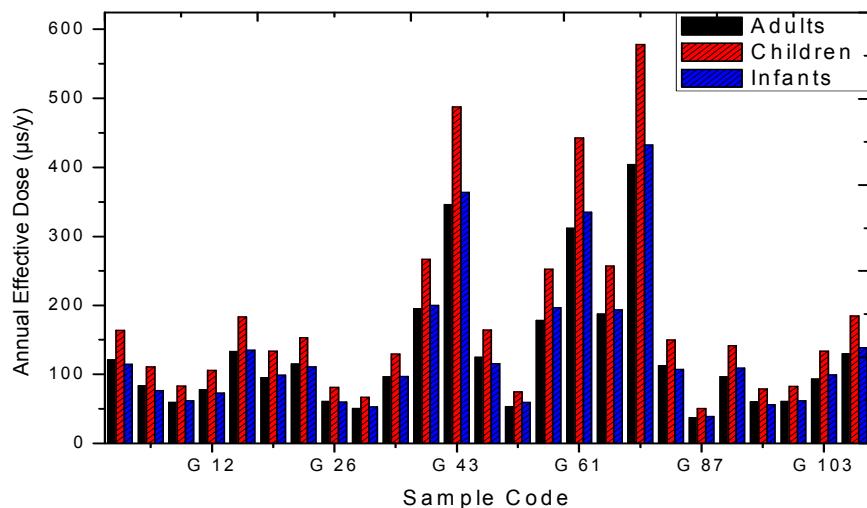


Figure 3. 20 The annual effective doses considering the ingestion of ^{222}Rn , ^{226}Ra and ^{232}Th radionuclides for different age groups in ground water

From the last figure, it is noted that, the doses received due to the ingestion of radionuclide's in ground water by children are higher than that received by infants and adults. Thus the age group at risk is children because of their intensive bone growth and action should be taken to restrict their intake. These values can be considered as important contributors to the daily incorporation of radionuclide's by ingestion, and it's also relevant when compared to the recommended reference level for the effective dose published by IAEA (IAEA 2002), from one year consumption of drinking water, the obtained doses due to ingestion of ^{222}Rn in ground water are less than the recommended reference level, consequently, Qena ground waters are acceptable for life-long human consumption.

3.6.2 Annual Effective Doses due to Ingestion of ^{222}Rn in Tap Water

The annual effective dose for different age groups, infants, children, and adults due to intake of ^{222}Rn in tap water were calculated and listed in the table 3. 17.

Table 3. 17 Annual effective doses ($\mu\text{Sv}/\text{y}$) for different age groups due to ingestion of ^{222}Rn in drinking tap water

Sample No.	^{222}Rn (Bq/l)	Annual Effective Dose		
		Adults	Children	Infants
D1	0.050±0.0150	0.251	0.352	0.528
D2	0.047±0.0206	0.235	0.328	0.492
D3	0.062±0.014	0.311	0.435	0.653
D4	0.057±0.0168	0.285	0.399	0.598
D5	0.075±0.0185	0.377	0.528	0.792
D6	0.051±0.0076	0.253	0.355	0.532
D7	0.057±0.0089	0.286	0.401	0.601
D8	0.054±0.0078	0.272	0.381	0.572
D9	0.036±0.0032	0.18	0.252	0.378
D10	0.073±0.0036	0.365	0.511	0.767
D11	0.056±0.0034	0.282	0.395	0.592
D12	0.026±0.0145	0.128	0.18	0.27
D13	0.054±0.0167	0.27	0.378	0.567
D14	0.063±0.0146	0.317	0.443	0.665
D15	0.04±0.0066	0.2	0.281	0.421
D16	0.035±0.0022	0.177	0.248	0.372

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D17	0.046±0.0024	0.23	0.322	0.483
D18	0.057±0.0025	0.283	0.396	0.594
D19	0.044±0.0024	0.221	0.309	0.463
D20	0.044±0.0024	0.222	0.311	0.466
D21	0.047±0.0048	0.235	0.329	0.494
D22	0.035±0.0048	0.174	0.243	0.365
D23	0.053±0.005	0.264	0.369	0.554
D24	0.026±0.0047	0.131	0.183	0.275
D25	0.047±0.0013	0.235	0.329	0.493
D26	0.061±0.0016	0.307	0.43	0.645
D27	0.048±0.0013	0.238	0.333	0.499
D28	0.042±0.0012	0.21	0.294	0.441
D29	0.046±0.0012	0.232	0.324	0.487
D30	0.062±0.0015	0.31	0.434	0.651
D31	0.063±0.0016	0.314	0.44	0.66
D32	0.061±0.0015	0.307	0.43	0.645
D33	0.057±0.0015	0.284	0.398	0.597
D34	0.062±0.0023	0.31	0.435	0.652
D35	0.091±0.0023	0.454	0.635	0.953
D36	0.061±0.0018	0.307	0.43	0.644
D37	0.062±0.0018	0.312	0.437	0.656
D38	0.08±0.0019	0.401	0.561	0.841

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D39	0.053±0.0018	0.265	0.371	0.557
D40	0.068±0.0017	0.342	0.478	0.717
D41	0.065±0.0029	0.327	0.458	0.686
D42	0.044±0.0026	0.222	0.31	0.466
D43	0.064±0.0029	0.319	0.446	0.67
D44	0.064±0.0016	0.318	0.445	0.668
D45	0.068±0.0017	0.341	0.478	0.717
D46	0.091±0.0022	0.455	0.638	0.956
D47	0.073±0.0018	0.367	0.514	0.771
D48	0.063±0.0016	0.317	0.444	0.665
D49	0.038±0.0011	0.19	0.266	0.399
D50	0.085±0.0032	0.425	0.595	0.893
D51	0.049±0.0013	0.246	0.344	0.516
D52	0.05±0.0014	0.251	0.352	0.528
D53	0.068±0.0018	0.339	0.474	0.711
D54	0.061±0.0018	0.306	0.428	0.642
D55	0.072±0.0018	0.359	0.502	0.754
D56	0.067±0.0017	0.336	0.47	0.705
D57	0.066±0.0017	0.33	0.462	0.694
D58	0.062±0.0016	0.31	0.434	0.651
D59	0.077±0.0024	0.387	0.542	0.813
D60	0.056±0.0021	0.278	0.389	0.584

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D61	0.04±0.0018	0.199	0.278	0.418
D62	0.041±0.0013	0.203	0.284	0.426
D63	0.057±0.0014	0.286	0.401	0.601
D64	0.046±0.0012	0.23	0.322	0.483
D65	0.055±0.0014	0.273	0.383	0.574
D66	0.052±0.0013	0.259	0.362	0.543
D67	0.05±0.0013	0.248	0.348	0.521
D68	0.078±0.0018	0.389	0.545	0.817
D69	0.06±0.0014	0.3	0.419	0.629
D70	0.052±0.0013	0.262	0.367	0.551
D71	0.059±0.0015	0.294	0.412	0.617
D72	0.115±0.0028	0.574	0.804	1.205
D73	0.118±0.0027	0.588	0.823	1.235
D74	0.062±0.0016	0.31	0.434	0.651
D75	0.022±0.0007	0.112	0.157	0.236
D76	0.043±0.0011	0.215	0.302	0.452
D77	0.061±0.0014	0.306	0.429	0.643
DC1	0.016±0.0006	0.082	0.115	0.172
DC2	0.012±0.0006	0.062	0.086	0.129
DC3	0.022±0.0007	0.109	0.153	0.23
DC4	0.008±0.0005	0.041	0.058	0.086
DC5	0.02±0.0007	0.099	0.139	0.209

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DC6	0.006±0.0005	0.032	0.045	0.068
DC7	0.018±0.0007	0.091	0.128	0.192
DC8	0.006±0.0005	0.031	0.043	0.064
DC9	0.026±0.0008	0.132	0.185	0.278
DC10	0.012±0.0006	0.06	0.084	0.127
DC11	0.02±0.0007	0.101	0.141	0.211
DC12	0.012±0.0006	0.062	0.086	0.13
DC13	0.027±0.0008	0.135	0.189	0.283
DC14	0.011±0.0006	0.055	0.077	0.115
DC15	0.03±0.0009	0.151	0.211	0.316
DC16	0.018±0.0007	0.09	0.126	0.188
DC17	0.024±0.0008	0.119	0.167	0.25
DC18	0.013±0.0006	0.066	0.093	0.14
DC19	0.014±0.0006	0.07	0.098	0.147
DC20	0.008±0.0005	0.042	0.059	0.088
Minimum	0.006±0.0005	0.031	0.043	0.064
Maximum	0.117±0.002	0.588	0.823	1.235
Average	0.049±0.003	0.246	0.345	0.517

The obtained values of the annual effective dose of tap water due to ingestion of ^{222}Rn were ranged between 0.031 to 0.588, 0.043 to 0.823 and 0.064 to 1.235, with averages values of 0.246, 0.345 and 0.517 $\mu\text{Sv}/\text{y}$, for adults, children and infants, respectively. The annual effective doses for the different age groups "adults, children, and infants" are presented in the following figure 3. 21.

It is noted that, the received doses due to the ingestion of ^{222}Rn in Qena drinking tap water by infants are higher than that received by children and adults. According to the recommended reference level of 0.26, 0.2 and 0.1 mSv/y for effective dose for infants, children and adults respectively, published by IAEA (IAEA 2002), from one year consumption of drinking water, it is noted that the obtained doses due to ingestion of ^{222}Rn in drinking tap water are less than the recommended reference level, consequently, Qena drinking tap waters are acceptable for life-long human consumption.

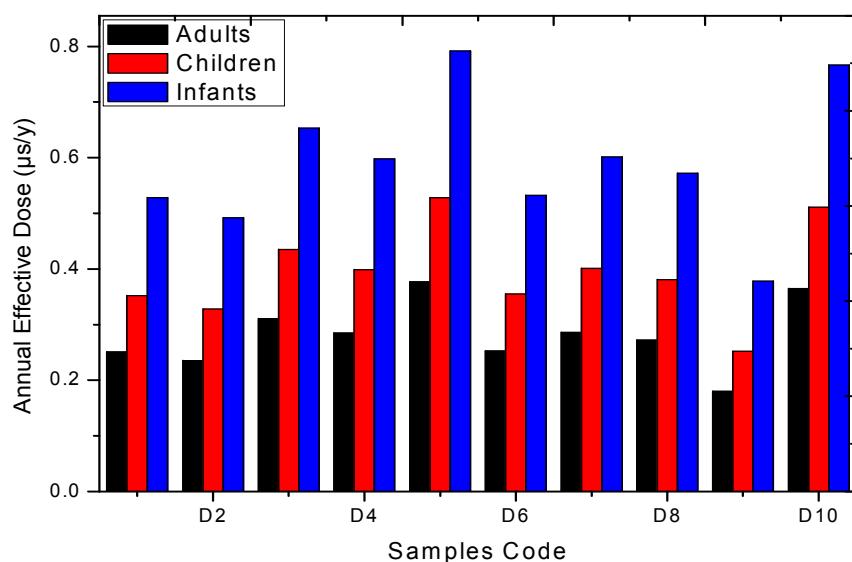


Figure 3. 21 The annual effective doses for different age groups due to ingestion of ^{222}Rn in drinking tap water for some samples

3.6.3 Annual Effective Doses due to Ingestion of ^{222}Rn in the Mineral water

The annual effective dose for different age groups, "infants, children and adults" due to intake of ^{222}Rn in the mineral water were calculated and listed in the following table 3. 18.

Table 3. 18 The Annual effective doses ($\mu\text{Sv}/\text{y}$) for different age groups due to ingestion of ^{222}Rn in the mineral water

Sample No.	Sample Name	$^{222}\text{Rn} (\text{Bq/l})$	Annual Effective Doses		
			Adults	Children	Infants
M1	Baraka	0.078 \pm 0.0013	0.388	0.544	0.816
M2	Dassani	0.014 \pm 0.0037	0.071	0.099	0.148
M3	Aquafina	0.055 \pm 0.0053	0.277	0.388	0.582
M4	Shiwips	0.177 \pm 0.0070	0.251	0.351	0.527
M5	Nestleh	0.237 \pm 0.0053	1.187	1.661	2.492
M6	Aqua delta	0.115 \pm 0.0026	0.574	0.803	1.205
M7	Siwa	0.030 \pm 0.0010	0.151	0.212	0.317
M8	Aqua	0.017 \pm 0.0005	0.083	0.116	0.174
M9	Hayah	0.062 \pm 0.0015	0.311	0.435	0.653
M10	Aqua Paris	0.019 \pm 0.0006	0.094	0.131	0.197
M11	Aqua Siwa	0.020 \pm 0.0007	0.098	0.137	0.205
M12	Vera	0.072 \pm 0.0016	0.36	0.504	0.76
M13	Nahl	0.026 \pm 0.001	0.132	0.185	0.278
M14	Aman Siwa	0.160 \pm 0.002	0.8	1.22	1.68
Minimum		0.014 \pm 0.003	0.071	0.098	0.148
Maximum		0.237 \pm 0.005	1.18	1.66	2.49
Average		0.077 \pm 0.002	0.386	0.54	0.81

The obtained values of the annual effective doses due to ingestion ^{222}Rn in the bottles mineral water were ranged between 0.071 to 1.187, 0.099 to 1.661 and 0.148 to 2.492, with average values of 0.355, 0.496 and 0.745 $\mu\text{Sv}/\text{y}$, for adults, children and infants, respectively. The maximum value for the annual effective dose was observed in the mineral water bottle Nestleh, whereas the minimum was observed in the mineral water bottle Dassani. The annual effective dose values for the different age groups "adults, children and infants" are presented in the figure 3. 22.

According to the recommended reference level of 0.26, 0.2 and 0.1 mSv/y for effective dose for infants, children and adults respectively, published by IAEA (IAEA 2002), from one year consumption of drinking water, it is noted that the obtained doses due to ingestion of ^{222}Rn in the mineral water are less than the recommended reference level, consequently, , the investigated bottles mineral water in Qena governorate, Egypt, are acceptable for life-long human consumption.

Table 3.19 shows comparison between the annual effective doses for different age groups due to ingestion of natural radionuclide's in the different kinds of water, which presented in this study.

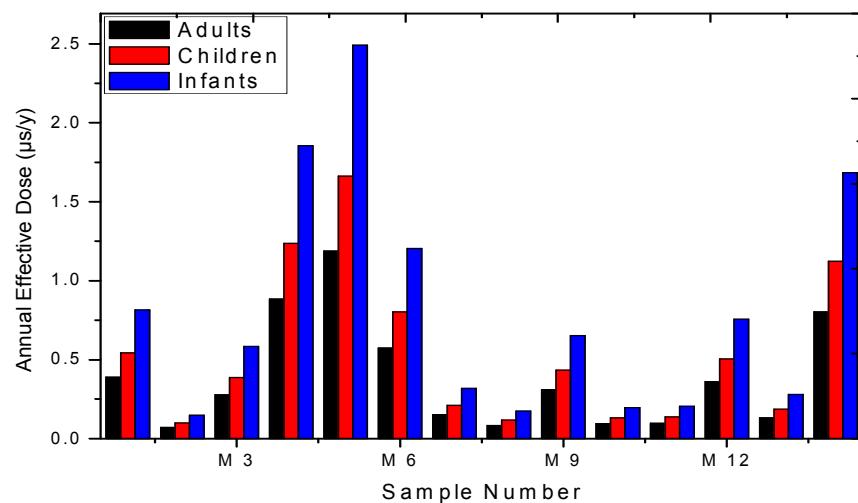


Figure 3. 22 The annual effective dose for different groups due to ingestion of ^{222}Rn in the mineral water

Table 3. 19 Comparison between the annual effective doses ($\mu\text{Sv}/\text{y}$) for different age groups due to ingestion of natural radionuclide's in the different kinds of water

Water Type	Adults			Children			Infants		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Ground Water	403.85	37.1	131.4	578	50.4	182.2	432.53	39	135.5
Tap Water	0.588	0.112	0.29	0.823	0.157	0.4	1.235	0.236	0.61
Mineral Water	1.186	0.071	0.386	1.66	0.098	0.541	2.49	0.148	0.812

SUMMARY

&

CONCLUSION

SUMMARY & CONCLUSION

Regarding to the great benefits from the studies of natural radioactivity and to continue the program of measuring natural radioactivity in different environmental media started in the Environmental Radioactivity Measurements Laboratory (ERML), Faculty of Science, south valley university, Qena, Egypt since 1990, measurement of natural radioactivity and radon levels in water samples from Qena governorate, Egypt were considered in this thesis.

This work is mainly concerned with many issues:

- The first concern is to investigate the ^{222}Rn activity concentrations in different kinds of water (ground water and drinking water) using Ionization Chamber "Alpha GUARD".
- The second concern is to investigate ^{222}Rn activity concentrations in ground water using gamma spectroscopy, and make a comparison between the two ^{222}Rn measurements techniques results.
- The third concern is to investigate the activity concentrations of natural radionuclides in the ground water samples. Such as ^{40}K , as well as radionuclides from the ^{226}Ra and ^{232}Th series.
- The fourth concern, the study makes it possible to study the correlations between the geochemical parameters such as PH, TDS and conductivity, with the activity concentrations of ^{222}Rn , ^{226}Ra , ^{232}Th and ^{40}K in water samples.
- Finally, ^{222}Rn and the natural radionuclides are considered as external sources of radiation to the human body. So this study estimate the annual effective dose for human by intake ^{222}Rn gas and the natural radionuclides ^{226}Ra , ^{232}Th and ^{40}K . Addition to make a comparison between the obtained results and the other published data.

4.1 The Measured Samples

Two hundred and twenty water samples from different sites in Qena governorate, have been collected, prepared, and measured at the Environmental Radioactivity Measurements Laboratory (ERML). These samples were classified as follow:

- 109 Ground water samples were collected from different sites in Qena, east and west of the Nile River.
- 97 Drinking Tap water samples were collected from Qena.
- 14 kinds of bottles water samples were collected from Qena markets.

4.1.1 The Samples for Alpha GUARD Measurements

4.1.1.1 Ground Water Samples

During the samples collection, the site was recorded preciously using the global positioning system (GPS). The geochemical parameters of water such as PH, conductivity and total dissolved solids “TDS” were measured in the field using portable SensoDirect PH 200 and Jenway Model 4520 Laboratory Conductivity/TDS Meter. At each site the well tap was opened, and the water was allowed to run for at least 20 minutes before the sample filling. The samples were stored in bottles with volume 500 ml or more, that which completely.

During the process of samples transferring from the field to laboratory, the samples were placed inside a closed box, away from direct sunlight. The samples were analyzed for radon as soon as possible after collection, the ^{222}Rn concentrations were estimated using Alpha EXPERT-WEW software, for evaluating the alpha spectra. All radon measurements were decay corrected to the time of sampling.

4.1.1.2 Drinking Water Samples

At each site in drinking tap water samples, the tap was opened, and the water was allowed to run for at least 20 minutes, the sample taken directly and slowly to the degassing vessel in the AquaKIT measuring system.

For the mineral water samples, every bottle was opened, and the sample was injected to degassing For the mineral water samples, every bottle was opened, and the

sample was injected to degassing vessel by the same method of the ground water measuring, ^{222}Rn activity concentrations in drinking tap and mineral water samples were estimated at the moment of usage, so the measurements were not corrected for the delay time.

4.1.2 The Samples for Gamma Spectroscopy Measurements

4.1.2.1 ^{222}Rn Activity Concentrations Measurements

Standard polyethylene Marinelli beakers (1.4 liters) were used as a sampling and measuring container. Firstly the containers were washed with dilute hydrochloric acid and rinsed with distilled water. Each Marinelli beaker was filled up to brim and a tight cap was pressed on so that the air was completely removed from it. ^{222}Rn concentrations in ground water samples are determined at least four hours after sampling, using gamma spectrometry based on an NaI(Tl) detector, ^{222}Rn concentration of ground water samples is assayed by 8 hour counting followed by analysis of gamma peaks using GENE 2000 software.

4.1.2.2 Natural Radionuclides Measurements

The same samples which have been measured for ^{222}Rn activity concentration by using gamma spectroscopy were stored for over one month to reach secular equilibrium between ^{226}Ra , ^{232}Th and their daughter products before radiometric analysis.

4.2 Measuring Systems

4.2.1 Alpha GUARD

The ionization chamber Alpha GUARD PQ2000PRO along with the additional special equipment AquaKIT was used for determining ^{222}Rn concentration in the water samples. The measuring system consists of two vessels (degassing and security), Alpha PUMP, Alpha GUARD, and the progeny filter. Prior to each measurement, the system is flushed with normal air until ^{222}Rn values are reached in the range of room air ^{222}Rn concentration.

The background of empty set-up was measured for a few minutes before every sample measuring. After that, the injected into the degassing vessel and the Alpha PUMP was switched on. All drops would deposit in the security vessel if they had got into the gas cycle during the degassing process. Through this way, the stress of the water vapor was minimized for the radon monitor. After 10 min the PUMP was switched off and the Alpha GUARD remained switched on for another 20 minutes, so the radon measurement was continued. This cycle was repeated three times in order to obtain a better precision. The Alpha GUARD monitor worked in a flow mode and ^{222}Rn concentration was recorded every 10 minute. The flow rate of the PUMP was 0.3 l/min.

4.2.2 Gamma Spectrometer

Low-level gamma ray spectrometer was used. It consists of "3x3" NaI (Tl). The system was calibrated for energy using standard point sources (^{60}Co , ^{137}Cs), and calibrated for efficiency using standard solution QCY48. Every sample was placed in face to face geometry over the detector for 8 hour for ^{222}Rn concentrations measurements, and for more than 24 hour for (^{226}Ra , ^{232}Th and ^{40}K) concentrations measurements.

Prior to sampling counting, background were normally taken every week under the same condition of sample measurement. The analysis of ^{222}Rn concentrations depends on the peaks of the decay products in equilibrium with their parent nuclides, it was measured from ^{214}Bi (609.32 keV) and ^{214}Pb (295, 351.92 keV).

The content of ^{226}Ra concentrations was measured using gamma-lines of ^{214}Bi (609.32, 1120 and 1765 KeV). The concentration of ^{232}Th was determined using gamma-lines of ^{228}Ac (911.16 KeV), and ^{212}Pb (238 KeV). The concentration of ^{40}K was determined by measuring its single peak at 1460.8 KeV.

4.3 ^{222}Rn Activity Concentrations in Ground Water Samples using Alpha GUARD

The study area was divided to four main areas, by geography method, depending on its location from the city of Qena.

The first region is Qift and Qus area, which locates in the south east of Qena. 26 samples from this area have been collected, prepared, and measured. The obtained values of ^{222}Rn concentrations in this area were fluctuated between 0.04 ± 0.025 and 4.97 ± 0.107 Bq/l, with an average value of 2.48 ± 0.054 Bq/l.

The second region is Nakada area, which locates in the south west of the city of Qena. 15 samples from this area have been collected, prepared, and measured. The obtained values of ^{222}Rn concentrations in this area were fluctuated between 0.65 ± 0.015 and 8.35 ± 0.187 Bq/l with an average value of 3.67 ± 0.079 Bq/l.

The Third region is Dishna area, which locates in the North east of the city of Qena. 13 samples from this area have been collected, prepared, and measured. The obtained values of ^{222}Rn concentrations in this area were fluctuated between 0.06 ± 0.002 and 7.22 ± 0.155 Bq/l, with an average value of 4.21 ± 0.091 Bq/l.

The Fourth region is Nagahammady and El-Waqf area, which locates in the North West of the city of Qena. 55 samples from this area have been collected, prepared and measured. The obtained values of ^{222}Rn activity concentrations in these area were fluctuated between 1.20 ± 0.027 and 10.07 ± 0.219 Bq/l, with an average value of 3.86 ± 0.084 Bq/l. Table 4.1 shows the statistical parameters of ^{222}Rn activity concentrations in the investigated ground water samples.

Table 4. 1 The statistical parameters of ^{222}Rn activity concentrations in ground water

Number of Samples	109
Minimum Activity	0.04 ± 0.025
Maximum Activity	10.07 ± 0.219
Arithmetic Mean	3.57 ± 0.077
Geometric Mean	2.87
Harmonic Mean	1.28
Median	3.14
Standard Deviation	2.06

It is evident that, the average values of ^{222}Rn concentrations are 2.48 ± 0.054 , 3.67 ± 0.079 , 4.21 ± 0.091 and 3.86 ± 0.08 Bq/l, in Qift and Qus, Nakada, Dishna, and Nagahammady and El-Waqf Areas, respectively, it is noted that, ^{222}Rn concentrations observed in low levels, due to the natural radioactivity of the subsoil in Qena area is generally low.

The maximum average value was observed in the Dishna area, which is due to that, this area is characterized by shortness of the area enclosed between mountainous areas and the river Nile, this mountainous region is characterized as close to Wadi Qena. Wadi Qena contain granite rocks, and found in a higher natural background than other regions in Upper Egypt, which leads to increase of activity concentrations of natural radionuclides in this area compared to the other three areas under study.

The correlations between ^{222}Rn concentrations in the samples with the water geochemical parameters (PH, conductivity and TDS) were examined. A reasonable correlation between PH and the content of ^{222}Rn concentrations was found, in which ^{222}Rn contents decreased with increasing PH. On the other hand no reasonable correlations between ^{222}Rn activity concentrations with the conductivity and TDS were observed.

4.3.1 ^{222}Rn Activity Concentrations in Ground Water using Gamma Spectroscopy

Make a comparison between the two radon measurements techniques is the main concern of this part from our study. The samples were collected from some ground water wells. These samples sites were taken by random method from the same sites which the ^{222}Rn activity concentrations by using Alpha GUARD were measured.

It is noted that, the two radon measurements techniques results are in a good agreement. In the most investigated samples, Alpha GUARD results are slightly higher than the obtained results from gamma spectrometry, due to that, the chance of radon escaping from samples to surrounding air in gamma spectroscopy technique is higher than Alpha GUARD technique, which is reflected on the lack of gamma spectroscopy results.

Another reason may leads to the higher results obtained from Alpha GUARD measurements than those results obtained from gamma spectrometer, ^{222}Rn concentrations in Alpha GUARD measuring technique were calculated due to directly registration of alpha particles, due to ^{222}Rn decay, but in gamma spectrometer measuring technique, ^{222}Rn concentrations were calculated due to ^{222}Rn daughters decay (^{214}Bi , ^{214}Pb), which leads to a high error rate in gamma results.

4.3.2 Natural Radionuclides Activity Concentrations in Ground Water

The obtained values of ^{226}Ra concentrations in Qift and Qus area were fluctuated between 0.126 ± 0.007 and 0.687 ± 0.034 Bq/l, with an average value of 0.41 ± 0.019 Bq/l. The obtained values of ^{232}Th concentrations in this area were fluctuated between 0.037 ± 0.003 and 0.601 ± 0.037 Bq/l, with an average value of 0.33 ± 0.021 Bq/l. The obtained values of ^{40}K concentrations in this area were found in higher values than ^{226}Ra and ^{232}Th concentrations, which fluctuated between 3.18 ± 0.273 and 6.39 ± 0.55 Bq/l, with an average value of 4.97 ± 0.43 Bq/l.

The obtained values of ^{226}Ra concentrations in Nakada area were fluctuated between 0.126 ± 0.007 and 1.205 ± 0.073 Bq/l, with an average value of 0.53 ± 0.034 Bq/l. The obtained values of ^{232}Th activity concentrations in this area were fluctuated between 0.128 ± 0.009 and 0.817 ± 0.07 Bq/l, with an average value of 0.39 ± 0.028 Bq/l. The obtained values of ^{40}K activity concentrations in this area were found in higher values, which fluctuated between 4.19 ± 0.36 and 6.45 ± 0.555 Bq/l, with an average value of 5.1 ± 0.43 Bq/l.

The obtained values of ^{226}Ra concentrations in Dishna area were fluctuated between 0.042 ± 0.002 and 1.54 ± 0.094 Bq/l, with an average value of 0.64 ± 0.034 Bq/l. The obtained values of ^{232}Th concentrations in this area were fluctuated between 0.068 ± 0.004 and 0.899 ± 0.077 Bq/l, with an average value of 0.42 ± 0.03 Bq/l. The obtained values of ^{40}K concentrations in this area were found in higher values, which fluctuated between 4.09 ± 0.351 Bq/l and 6.75 ± 0.581 Bq with an average value of 5.18 ± 0.44 Bq/l.

The obtained values of ^{226}Ra concentrations in Nagahammady and El-Waqf area were fluctuated between 0.123 ± 0.007 and 1.93 ± 0.117 Bq/l, with an average value of 0.58 ± 0.031 Bq/l. The obtained values of ^{232}Th concentrations in this area were fluctuated between 0.109 ± 0.007 and 0.872 ± 0.075 Bq/l, with an average value of 0.41 ± 0.028 Bq/l. The obtained values of ^{40}K concentrations in this area were found in higher values, which fluctuated between 3.5 ± 0.301 and 7 ± 0.602 Bq/l, with an average value of 5.17 ± 0.44 Bq/l. Table 4. 2 shows the statistical parameters of natural radionuclides activity concentrations in the investigated ground water samples.

Table 4. 2 The statistical parameters of natural radionuclides activity concentrations in ground water

Radionuclide	^{226}Ra	^{232}Th	^{40}K
Number of Samples	108	108	108
Minimum Activity	0.042 ± 0.002	0.067 ± 0.004	3.18 ± 0.273
Maximum Activity	1.93 ± 0.117	0.899 ± 0.077	6.99 ± 0.602
Arithmetic Mean	0.54 ± 0.029	0.4 ± 0.027	5.10 ± 0.44
Geometric Mean	0.44	0.331	5.05
Harmonic Mean	0.35	0.267	4.99
Median	0.47	0.352	5.078
Standard Deviation	0.35	0.209	0.77

From the obtained results it is noted that the ^{226}Ra , ^{232}Th and ^{40}K concentrations are varying in small and narrow range, this similarity comes from that the study area has the same geological properties and the natural radioactivity of the subsoil in Qena area is generally low. The maximum average values of natural radionuclides were observed in Dishna area. It should be noted that in all studied sites ^{226}Ra activity concentrations are higher than ^{232}Th concentrations, because ^{226}Ra is more soluble in ground water than its thorium and uranium precursors.

From the comparison between the obtained results and the other published data in the same area, it is evident that the investigated ground water samples have normal and similar values with the concentrations of ^{226}Ra , ^{232}Th and ^{40}K . An attempt was made to correlate the concentrations of ^{226}Ra , ^{232}Th and ^{40}K . A reasonable correlation was found between ^{226}Ra and ^{232}Th concentrations, and poor correlations between (^{40}K with ^{232}Th) and (^{40}K with ^{226}Ra) could be observed.

The correlations between ^{226}Ra , ^{232}Th and ^{40}K concentrations with the water geochemical parameters, (PH, conductivity and TDS) were examined. Reasonable correlations between PH and the content of ^{226}Ra and ^{232}Th concentrations were found in which ^{226}Ra and ^{232}Th concentrations decreased with increasing PH. On the other hand, no reasonable correlation between ^{40}K content and PH was observed. Also, no general trend was observed that related the activity concentrations of natural radionuclides with the conductivity and TDS. The correlation between ^{226}Ra concentrations and the measured ^{222}Rn concentrations in ground water samples were examined. It is noted that, there are a linear correlation was observed.

4.3.3 ^{222}Rn Activity Concentrations in Drinking Tap Water Samples

The obtained values were fluctuated between 0.006 ± 0.0005 and 0.117 ± 0.002 Bq/l with an average value of 0.049 ± 0.003 Bq/l. A set of drinking water samples have been compiled before and after the chemicals treatment process, it is noted that, the obtained results of ^{222}Rn concentrations for the samples before the treatment process are higher than those values obtained after the treatment process.

This low levels and the similarity between the obtained results is due to that, the river Nile is considered the main source of drinking tap water in Qena, and all this part samples come from the Nile river, after passing many analyzing processes, this give a chance to ^{222}Rn to escape from water surface, addition to, the open water contains very little dissolved radium, so we rarely find radon in significant concentrations in surface waters, due to its rapid dispersal into the atmosphere.

On the other hand no reasonable correlations between ^{222}Rn concentrations in Qena drinking tap water with the water geochemical parameters (conductivity and TDS)

were observed. Table 4.3 shows the statistical parameters of ^{222}Rn activity concentrations in the investigated tap water samples.

Table 4. 3 The statistical parameters of ^{222}Rn activity concentrations in tap water

Number of Samples	97
Minimum Activity	0.006±0.0005
Maximum Activity	0.117±0.002
Arithmetic Mean	0.049±0.003
Geometric Mean	0.042
Harmonic Mean	0.032
Median	0.052
Standard Deviation	0.023

4.3.4 ^{222}Rn Activity Concentrations in Mineral Water Samples

The obtained values of ^{222}Rn concentration in the mineral water were fluctuated between 0.014±0.003 and 0.237±0.005 Bq/l, with an average value of 0.077±0.002 Bq/l. From these results, it is noted that, all mineral water results for ^{222}Rn concentrations are small, due to that, the original sources of the measured mineral waters is ground water wells, in different places in Egypt, and this water passes many analyzing processes before using it for drinking, that give a chance for ^{222}Rn to escape from water, addition to that the half life time of ^{222}Rn is 3.82 day, so the gas will completely decay after a few weeks of extracting from the well.

Table 4. 4 shows the statistical parameters of ^{222}Rn activity concentrations in the investigated mineral water samples.

Table 4. 4 The statistical parameters of ^{222}Rn activity concentrations in mineral water

Number of Samples	14
Minimum Activity	0.014 ± 0.003
Maximum Activity	0.237 ± 0.005
Arithmetic Mean	0.077 ± 0.002
Geometric Mean	0.052
Harmonic Mean	0.036
Median	0.058
Standard Deviation	0.07

4.4 Annual Effective Doses

When analyzing the total annual effective dose to the human population from natural sources, the dose received by ingestion of ^{222}Rn and the long-lived natural radionuclides must be considered. Effective doses resulting from the intake of ^{222}Rn , ^{226}Ra , ^{232}Th and ^{40}K may be determined directly from external measurements of their concentrations in the body or estimated from concentrations in intake materials such as air, food and water. Intakes of ^{222}Rn and the natural radionuclides ^{226}Ra and ^{232}Th from different kinds of water in Qena governorate, Egypt were calculated, assuming the consumption rate and the conversion factors reported by ICRP and WHO. The calculation outcomes of dose rates are given in the following parts.

4.4.1 Annual Effective Doses due to Ingestion of Ground Water

The annual effective doses for different age groups "adults, children and infants" due to the ingestion of ground water in Qena, were calculated for some samples, which are used as a drinking water, considering only the ingestion from ^{222}Rn , ^{226}Ra and ^{232}Th . The obtained values of the annual effective doses were ranged between 37.1 to 403.85, 50.4 to 578 and 39 to 432.53, with average values of 131.4, 182.2 and 135.5 $\mu\text{Sv}/\text{y}$, for Adults, children and infants, respectively.

From the obtained results it is noted that, the doses received due to the ingestion of radionuclide's in ground water by children are higher than that received by infants and adults, thus the age group at risk is children because of their intensive bone growth and action should be taken to restrict their intake. These values can be considered as important contributors to the daily incorporation of radionuclide's by ingestion, and it's also relevant when compared to the recommended reference level, for the effective dose published by WHO and IAEA from one year consumption of drinking water, the obtained doses in the study of ground water in Qena, are lower than the recommended reference level, consequently, the investigated ground water in Qena governorate, Egypt, are acceptable for life-long human consumption.

4.4.2 Annual Effective Doses due to Ingestion of Drinking Tap Water

Considering ^{222}Rn concentrations in drinking tap water and habitual consumption, the human health risk from irradiation due to direct ingestion was assessed. It's observed that doses received by infants are higher than that received by children and adults. The obtained values of the annual effective dose of drinking tap water were ranged between 0.031 to 0.588, 0.043 to 0.823 and 0.064 to 1.235, with averages values of 0.246, 0.345 and 0.517 $\mu\text{Sv}/\text{y}$, for adults, children and infants, respectively. According to the recommended reference level for the annual effective dose, published by WHO and IAEA from one year consumption of drinking water. The obtained doses are lower than this recommended reference level, and consequently, we recommended that, the investigated tap waters are acceptable as drinking water for life-long human consumption.

4.4.3 Annual Effective Doses due to Ingestion of Mineral Water

Appling measured ^{222}Rn concentrations in mineral water and habitual consumption, the human health risk from irradiation due to direct ingestion was assessed. The obtained values of the annual effective doses due to ingestion ^{222}Rn in the mineral water were ranged between 0.071 to 1.187, 0.099 to 1.661 and 0.148 to 2.492, with average values of 0.355, 0.496 and 0.745 $\mu\text{Sv}/\text{y}$, for adults, children and infants, respectively. It's observed that doses received by infants are higher than that received by

children and adults. According to the recommended reference level for the annual effective dose, published by WHO and IAEA from one year consumption of drinking water, the doses obtained in this part are lower than those recommended reference level, and consequently, the investigated mineral waters are acceptable as drinking water for life-long human consumption.

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ARABIC SUMMARY

الملخص العربي

في إطار تنفيذ الخطة البحثية لمعمل قياسات الإشعاع البيئي بكلية العلوم – جامعة جنوب الوادي ، فقد قمنا في هذا العمل بتنفيذ أحد عناصر تلك الخطة وهو قياس مستوى النشاط الإشعاع البيئي ومستويات غاز الرادون لعينات من المياه من محافظة قنا بصعيد مصر ، حيث شملت تلك المياه كلاً من المياه الجوفية ومياه الشرب ومياه النيل والمياه المعدنية ، وذلك باستخدام الأجهزة المتاحة بالمعمل ومنها بشكل رئيسي جهاز أفالجارد وجهاز يوديد الصوديوم المطعم بالثاليلوم . من المعروف أنه يمكن تقسيم الإشعاع بعدة طرق مختلفة ، منها مثلاً الإشعاع المؤين والإشعاع غير المؤين ، الجسيمات وال WAVES ، الإشعاع الضار والإشعاع غير الضار .. الخ . ويتوارد الإشعاع في الطبيعة من حولنا في الأوساط المختلفة مثل الهواء والماء والتربة والصخور والنباتات . وتمثل السلسلة الإشعاعية الثلاثة ، اليورانيوم-238 والليورانيوم-235 والثورانيوم-232 المصدر الأساسي للنشاط الإشعاعي الطبيعي ، بالإضافة لعنصر البوتاسيوم-40 . وتمثل تلك النوبيات المشعة خطراً كبيراً على صحة الإنسان ، حيث يمكنها دخول الجسم البشري بعدة طرق مختلفة منها مثلاً الأكل أو الشرب أو التنفس أو التعرض الخارجي ، حيث تخترق أعضاء الجسم وصولاً للخلايا مسببة تلفها ، وهو ما يؤدي بدوره للإصابة بمرض السرطان . ولذلك أصبحت دراسات النشاط الإشعاعي وتقدير الأضرار التي يتعرض لها الإنسان محل اهتمام كبير جداً خصوصاً في السنوات الأخيرة . غاز الرادون هو أحد نواتج سلسلة اليورانيوم-238 ، وهو غاز خامل عديم اللون والرائحة ، عمره النصفـي 3.82 يوم ، ويعتبر أخطر النوبيات المشعة الموجودة في الطبيعة بتمثيله لحوالي نصف نسبة الجرعة الإشعاعية الكلية التي يتعرض لها الإنسان ، وطبقاً لتقرير منظمة الصحة العالمية يعتبر هذا الغاز واحداً من أهم مسببات مرض السرطان .

عينات الدراسة

تقوم تلك الدراسة على قياس النشاط الإشعاعي الطبيعي ومستويات غاز الرادون للمياه في محافظة قنا وذلك بتجميع 220 عينة مياه تم تقسيمها لثلاث أنواع :

- 109 عينة مياه أبار جوفية
- 97 عينة مياه شرب
- 14 عينة مياه معدنية

تجهيز العينات للقياس

أولاً : قياس الشدة الإشعاعية لغاز الرادون في عينات المياه الجوفية باستخدام جهاز الفاجارد

في كل موقع من مواقع العينات يتم ترك صنبور البئر مفتوح لمدة لا تقل عن 20 دقيقة ، حتى يتم التأكد من أن المياه تأتي مباشرة من البئر وألا تكون متراكمة في مواسير السحب . وتملأ العينة في عبوات يتم تعبئتها للنهاية مع مراعاة عدم وجود أي فراغات بين العينة وبين غطاء العبوة وذلك منعاً لتسرب الغاز ، وتنتمي عملية نقل العينات من مكان التجميع للمعمل باستخدام صندوق مغلق بعيداً عن أشعة الشمس المباشرة لتجنب ارتفاع درجة حرارة العينات ، ويتم قياس العينات في أسرع وقت بعد التجميع لتجنب فقدان الغاز نتيجة لحدوث عملية الإنحلال . وبعد قياس العينات يتم حساب فارق الزمن بين وقت التجميع ووقت القياس ومن ثم إجراء عمل تصحيح التركيز بالنسبة للزمن .

ثانياً : قياس الشدة الإشعاعية لغاز الرادون في عينات مياه الشرب والمياه المعدنية بـ باستخدام الأف جارد

بالنسبة لعينات مياه الشرب يتم فتح صنبور المياه لمدة لا تقل عن 20 دقيقة ، ويتم التأكد من أن خراطيم التوصيل لا تحتوي على أي فقاعات هواء ، وتملأ عبوة العينة ببطء في نظام القياس ، وبالنسبة لعينت المياه المعدنية تفتح عبوة المياه وتنتقل باستخدام المحقق ببطء أيضاً لعبوة العينة . ويتم في كلا النوعين حساب تركيز غاز الرادون وقت الاستخدام وعدم عمل أي تصحيح بالنسبة للزمن .

ثالثاً : قياس الشدة الإشعاعية لغاز الرادون في المياه الجوفية باستخدام مطياف جاما

يتم تعبئة العينات في عبوات خاصة (Marinelli beaker) ذات سعة 1.4 لتر ، يتم غسلها أولاً باستخدام حمض هيدروكلوريك مخفف لإزالة أي أملاح عالقة بجدران الإناء ، وبعدها يتم مليء العينة حتى نهاية الحد العلوي ، وللتخلص من أي آثار للهواء يتم الضغط على السطح العلوي لعبوة مع مراعاة إحكام غلقها جيداً ، ويتم قياس العينات بعد ساعتين من التجميع لمدة 8 ساعات .

رابعاً : قياس الشدة الإشعاعية لكلا من الراديوم-226 والثوريوم-232 والبوتاسيوم-40 في عينات المياه الجوفية باستخدام مطياف جاما الوميسي (NaI (Tl)

نفس العينات التي تم تجميعها لقياس تركيز غاز الرادون بإستعمال مطياف جاما يتم تخزينها لمدة شهر للوصول لحالة الاتزان بين تلك النويات ونواتج إنحلالها قبل بدء قياسها مرة أخرى على مطياف جاما لمدة لا تقل عن 24 ساعة .

طرق القياس

تقوم الدراسة على استخدام طريقتين مختلفتين لقياس النشاط الإشعاعي في عينات المياه :

الطريقة الأولى: تم إستعماله لقياس تركيز غاز الرادون في الأنواع المختلفة من المياه ، وهو عبارة عن جهاز غرفة التأين ألفاجارد ، المصحوب بالوحدة أوكاكيت ، ويعتمد ذلك الأسلوب على إستخراج الغاز من العينة بإستعمال مضخة للهواء عرضها إحداث تقليل للعينة وضخ الغاز داخل غرفة التأين بإستخدام مجموعة من أنابيب التوصيل بعد مروره بمجموعة من الفلاتر ، تعمل على تنقية الغاز من حبيبات التراب أو من الرطوبة ، وتسمح فقط لغاز الرادون بالمرور . وبدخول الغاز لغرفة التأين تتولد النسبة الكهربائية التي تحول لنسبة تناظرية يتم قراءتها من خلال برنامج الألفارجارد .

الطريقة الثانية: هو مطياف جاما والمكون من كاشف يوديد الصوديوم المطعم بعنصر الثاليوم ، والمتصل بمحلل عديد الفتوات . حيث تمت معايرته بإستخدام المصادر العيارية " السيزيوم 137 والكوبالت 60 " ، كما تم تقدير كفاءة الكاشف باستخدام مصدر عياري Qcy48 . أيضا تم قياس الخلفية الإشعاعية أسبو عيا ، وأجري تصحيح معدل العد لكل عينة مقاسة .

وقد تم تقدير تركيز غاز الرادون بإستعمال مطياف جاما من خلال قياس أشعة جاما المنبعثة من البزموت 214 بالطاقة 609.32 ، ومن الرصاص 214 بالطاقة 295 ، 352 ، ولقد تم تقدير الراديوم 226 من خلال قياس أشعة جاما المنبعثة من البزموت 214 بطاقة 609 ، 1120 ، 1765 . أما الثوريوم-232 فتم تقديره من الأكتينيوم-228 بالطاقة 911 ، والرصاص-212 بطاقة 238 . بينما البوتاسيوم 40 تم تقديره مباشرة من أشعة جاما ذات الطاقة 1460 ، حيث ان كل الطاقات مقدرة بوحدات أ.ف.

بالإضافة إلى قياس تركيز النويات السالفة الذكر ، تم قياس بعض الخواص الجيوكيميائية للعينات مثل الرقم الهيدروجيني والموصلية الكهربائية ومجمل الأملاح الذائبة ، وتمت تلك القياسات حفليا بإستخدام جهازين أحدهما لقياس الرقم الهيدروجيني والأخر لقياس الموصلية الكهربائية ومجمل الأملاح الذائبة ، وأيضا تم تحديد موقع الآبار قيد الدراسة بدقة باستخدام جهاز تحديد الموقع .

نتائج البحث

أظهرت نتائج قياس الشدة الإشعاعية لغاز الرادون في المياه الجوفية باستخدام جهاز الأفاجارد أن الشدة بوحدة البيكريل/لتر تتراوح ما بين 0.04 ± 0.025 إلى 10.07 ± 0.219 ، بقيمة متوسطة 3.57 ± 0.077 . تمت أيضا دراسة العلاقة بين تركيز غاز الرادون وبين الخواص الجيوكيميائية لعينات المياه قيد البحث ، وتبين وجود علاقة عكسية بين تركيز الغاز وبين الرقم الهيدروجيني للعينات ، في حين لم يتبيّن وجود أي علاقة بين تركيز غاز الرادون وبين الموصلية الكهربائية أو مجلل الأملاح الذائبة .

لعمل مقارنة بين للأسلوبين المختلفين لقياس الشدة الإشعاعية لغاز الرادون وهما غرفة التأين ألفا جارد ومطياف جاما ، تم اختيار مجموعة من العينات بطريقة عشوائية من موقع العينات التي تم قياس تركيز غاز الرادون فيها بإستعمال جهاز الأفاجارد ، وتم تجهيزها وإعدادها لقياس تركيز الرادون فيها بإستعمال مطياف جاما ، حيث أظهرت النتائج أن الشدة الإشعاعية لغاز الرادون بالبيكريل/لتر تتراوح ما بين 0.48 ± 0.02 و 5.2 ± 0.32 ، بقيمة متوسطة 2.29 ± 0.13 . حيث بينت الدراسة أن التركيزات المتحصل عليها بكلتا الطريقتين متقاربة جدا ، وان كانت النتائج المتحصل عليها بإستعمال جهاز الأفاجارد تبدو أعلى قليلا في معظم العينات المقابلة ، إلا أن هذا الفارق يمكن إهماله في التركيزات العالية للرادون .

أسفر قياس النشاط الإشعاعي لعينات المياه الجوفية عن تراوح قيم الشدة الإشعاعية بالبيكريل/لتر للراديوم ما بين 0.042 ± 0.002 و 1.93 ± 0.117 ، بقيمة متوسطة 0.54 ± 0.029 ، بينما تراوحت الشدة الإشعاعية للثوريوم بين 0.067 ± 0.004 و 0.899 ± 0.077 ، بقيمة متوسطة 0.4 ± 0.027 . بينما تراوحت قيم الشدة الإشعاعية للبوتاسيوم بين 3.18 ± 0.273 و 6.99 ± 0.602 ، بقيمة متوسطة 5.10 ± 0.44 . تم أيضا دراسة العلاقة بين الشدة الإشعاعية للنيويات المشعة وبين الخواص الجيوكيميائية لعينات المياه الجوفية قيد البحث ، وتبين وجود علاقة عكسية بين تركيز كل من الراديوم والثوريوم وبين الرقم الهيدروجيني . في نفس الوقت بينت الدراسة عدم وجود علاقة بين تركيز البوتاسيوم وبين الرقم الهيدروجيني . وأيضا لم يستدل على وجود أي علاقة واضحة تربط تركيز النيويات المشعة وبين الموصلية الكهربائية أو مجلل الأملاح الذائبة . وأيضا أظهرت نتائج قياس الشدة الإشعاعية لغاز الرادون لعينات مياه الشرب في محافظة قنا أن قيم التركيزات بالبيكريل/لتر تتراوح ما بين 0.006 ± 0.0005 و 0.117 ± 0.002 ، بقيمة متوسطة 0.049 ± 0.003 .

تم قياس مجموعة من عينات مياه الشرب قبل وبعد دخولها لعملية المعالجة الكيميائية داخل محطة مياه الحميدات ومن النتائج المتحصل عليها وجدنا ان عينات المياه بعد دخول عملية المعالجة تعطي نتائج أقل من ذي قبل . تمت أيضا دراسة العلاقة بين تركيز غاز الرادون في عينات مياه الشرب المقاسة وبين والخواص الجيوكيميائية مثل مجمل الأملاح الذائبة والموصولة وتبيّن عدم وجود أي علاقة بينهم . كما أظهرت نتائج قياس الشدة الإشعاعية لغاز الرادون لعينات المياه المعدنية في محافظة قنا أن قيم التركيزات بالبيكيل/لتر تتراوح ما بين 0.014 ± 0.003 الي 0.237 ± 0.005 ، بقيمة متوسطة 0.077 ± 0.002 .

حسابات الجرعة

تم تقدير الخطر الناتج عن استخدام هذه الأنواع المختلفة من المياه قيد الدراسة ، وذلك عن طريق حساب الجرعة السنوية الناتجة من إبتلاع كلا من الرادون والراديوم والثوريوم ، والمتواجدة في هذه المياه ، وذلك للفئات العمرية المختلفة " الرضع والأطفال والبالغين " . وأسفرت الحسابات على أن قيم الجرعة السنوية التي يتلقاها الإنسان نتيجة لتناول المياه الجوفية بالميكروسيفرت/سنة لكلا من البالغين والأطفال والرضع تتراوح بين 8.86 الي 403.85 ومن 11.34 الي 578 ومن 7.22 الي 578 ، بقيم متوسطات 126.68 ، 175.65 ، 130.6 للفئات العمرية الثلاثة علي الترتيب . وأظهرت الدراسة أن قيم الجرعة السنوية ناتجة لتناول مياه الشرب من صنابير المياه في محافظة قنا تتراوح من 0.112 إلى 0.588 ومن 0.157 الي 0.823 ومن 0.236 الي 1.235 ، بمتوسطات 0.29 ، 0.41 ، 0.61 للفئات العمرية الثلاثة علي الترتيب . أما الجرعات الناتجة عن تناول المياه المعدنية للفئات العمرية الثلاثة بالميكروسيفرت/سنة فتراوحت قيمها بين 0.071 إلى 1.187 ومن 0.099 الي 1.661 ومن 1.0146 الي 2.492 بمتوسطات 0.312 ، 0.44 ، 0.65 علي الترتيب .

وبمقارنة قيم الجرعات المتحصل عليها من دراستنا بالقيمة المسموح بها طبقا لتقرير منظمة الصحة العالمية لسنة 1996 وتقرير الوكالة الدولية للطاقة الذرية لسنة 2002 يتضح أن قيم الجرعة السنوية المحسوبة لعينات الأنواع المختلفة لمياه الشرب في محافظة قنا أقل من القيمة المسموح بها مما يدل علي عدم وجود أي خطورة علي صحة الانسان من الناحية الاشعاعية .

الملخص العربي



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قسم الفيزياء
كلية العلوم

رسالة ماجستير:

إسم الطالب : خالد علي محمد علي

عنوان الرسالة : النشاط الإشعاعي الطبيعي لعينات مختلفة من المياه بمحافظة قنا

الدرجة العلمية : الماجستير

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- 1
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/ / تاريخ المناقشة

أجازت الرسالة بتاريخ / / ختم الإجازة



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سنة التخرج : 2007
سنة المنح :

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَقُلْ رَبِّي أَدْخِلْنِي مَدْخَلَ صَدَقٍ

وَأَخْرِجْنِي مَذْرِعَ صَدَقٍ وَاجْعَلْ لِي مِنْ

لَدْنِكَ سُلْطَانًا نَصِيرًا

صَدَقَ اللَّهُ الْعَظِيمُ



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رسالة مقدمة إلى

كلية العلوم بجامعة جنوب الوادي
للحصول على درجة الماجستير في الفيزياء
مقدمة من
خالد علي محمد علي
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2014